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ABSTRACT

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Large-scale composting is a proven method by which Anderson County can demonstrate sound environmental stewardship while drastically reducing the volume of waste entering county landfills, thereby extending their usable life. However, the major aspects of planning, constructing, and operating a municipal yard waste composting facility must be fully understood before undertaking such an endeavor. Subsequently, this research contains comprehensive information on the principles of composting in an effort to assist Anderson County in creating the cost-effective means to produce a consistently high-quality and marketable end product.

With the capability to create significant reductions in current MSW disposal rates while generating a positive image for Anderson County, municipal composting is a worthwhile and potentially profitable venture. Not only will large-scale composting help build a sustainable future for South Carolina, but it may even encourage participation in other county recycling programs.

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December 12, 2003

To the Graduate School:

This thesis entitled "Design of a Municipal Yard Waste Composting Facility for Anderson County, South Carolina" and written by Michael E. Klapmeyer is presented to the Graduate School of Clemson University. I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science with a major in Environmental Engineering and Science.

Thomas J. Overcamp

Thomas J. Overcamp, Thesis Advisor

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DESIGN OF A MUNICIPAL YARD WASTE COMPOSTING FACILITY FOR ANDERSON COUNTY, SOUTH CAROLINA

A Thesis

Presented to

the Graduate School of

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by

Michael Evan Klapmeyer

December 2003

Advisor: Dr. Thomas J. Overcamp

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CHAPTER 1

INTRODUCTION

According to a recent Environmental Protection Agency study, the national average for yard waste entering the municipal solid waste (MSW) stream is 12 percent by weight (U.S. EPA, 2002a). In fact, yard waste is the second largest contributor to this country's solid waste stream following paper. Although an estimated 27.73 million tons of yard waste is generated per year, not all is disposed in landfills (U.S. EPA, 2002a). An increasing number of states have passed legislation banning the disposal of yard waste in landfills, resulting in the ultimate disposal of 11.96 million tons, or 7 percent by weight (U.S. EPA, 2002a). Currently, South Carolina regulations ban yard materials from MSW landfills. However, South Carolina allows for yard materials to be buried in construction and demolition (C&D) landfills, thereby giving many counties in the state an apparently inexpensive loophole for yard waste disposal (Williams, 2003). Anderson County, South Carolina, is one such county.

Situated halfway between Atlanta and Charlotte along Interstate 85, Anderson County is a 758 square mile area comprised of a burgeoning community of roughly 170,000 residents in and around the municipalities of Anderson, Belton, Honea Path, Iva, Pelzer, Pendleton, Starr, West Pelzer, and Williamston (Epps, 2003 and Anderson County Chamber of Commerce, 2003). Together, Anderson County residents send more than 105,000 tons of MSW to local landfills each year, including 20,000 tons of yard waste discarded in the Starr C&D Landfill (Rollins, 2003). This yard waste constitutes

19 percent of the total discarded MSW, making Anderson County's disposal of yard waste a staggering 270 percent above the national average of 7 percent.

In general, solid waste disposal has become a pressing issue of concern for counties throughout South Carolina. With yard waste consuming a large portion of available landfill space, coupled with the increasing cost of siting and constructing new landfills, local authorities must grapple with alternative methods of meeting the waste disposal challenge. Municipal yard waste composting is one such way by which local governments can demonstrate sound environmental stewardship while drastically reducing the volume of waste entering landfills, thereby extending their usable life.

Scope of Research

The major objective of this research is to provide Anderson County with comprehensive information on all aspects of planning, constructing, and operating a municipal yard waste composting facility. This information will ultimately enable local officials to decide if operating such a facility is feasible in lieu of current practices. And, if feasible, give facility operators a comprehensive review of the most advantageous process management techniques for producing a quality end product. Specific aspects of this research include:

- Highlighting various composting phases from a microbiological standpoint.
- Quantifying the physical parameters that govern the composting process and discussing their associated effects on microbial activity.
- Calculating the volume of end product based on incoming feedstock, to include the production of mulch from partially decomposed wood chips.

- Exploring the various technologies associated with municipal yard waste composting, proposing several implementation options, and recommending the most viable option for Anderson County.
- Properly siting the facility based on government regulations, as well as determining facility size based upon the technology selected and the amount of incoming yard waste.
- Identifying costs associated with site development, construction, equipment acquisition, manpower, and daily operation for each type of technology considered.
- Determining the likelihood of adverse human health, environmental, and/or aesthetic effects associated with both the production and use of compost.
- Thoroughly investigating the causes and proper management of odor in composting operations, to include issues surrounding the incorporation of grass clippings into compost operations.
- And, identifying potential end users of compost and discussing possible barriers to a profitable market.

Significance of Research

As stated previously, this research aims to provide Anderson County with the means to construct and operate a cost-effective municipal yard waste composting facility. Not only will this further demonstrate the county's forward-thinking resourcefulness that earned it the distinctive "All American City" award in 2000, but it will drastically reduce the substantial volume of yard waste currently entering the county's C&D landfill, thereby extending its usable life.

CHAPTER 2

BENEFITS OF COMPOSTING

In their *Field Guide to Compost Use*, the U.S. Composting Council (2000) defines compost as "the product resulting from the controlled biological decomposition of organic material that has been sanitized through the generation of heat and stabilized to the point that it is beneficial to plant growth. Compost is an organic matter source that has the unique ability to improve the chemical, physical, and biological characteristics of soils or growing media." Scores of landscapers and gardeners are acutely aware of this unique ability, referring to compost as "black gold" to describe its many positive attributes. From soil amendment to landfill cover, the vast benefits and uses of compost are described below.

Economic Benefits

Diverting yard waste from C&D landfills reduces the amount of solid waste managed through disposal, subsequently extending the life of the landfill. This diverted yard waste can then be converted into compost, which can be sold to residential and commercial markets for a potential profit. This diversion also delays the significant fees associated with landfill closure along with the expense of siting and constructing a new landfill (SC DHEC, 2002a).

In addition to economic benefits realized by a municipality, compost also makes good economic sense for the consumer. Compost provides supplemental nutrients to the soil that aids in plant growth, contributing nitrogen, phosphorus, potassium, and many trace minerals. These additions act as a nutrient supplement, thereby saving money

by decreasing the need to purchase conventional amounts of a balanced inorganic fertilizer (Ball, 1997).

Soil Benefits

Clay soils are abundant in Anderson County and throughout the upstate of South Carolina. Particles in clay soil are very fine and pack together densely. While this is good for holding nutrients and water, it leaves little pore space for the infiltration of air. This lack of space also affects the growth of plants, making it difficult for newly formed roots to grow and move through the soil in search of necessary moisture and nutrients (Ball, 1997).

Conversely, particles that make up sandy soils are characteristically larger, coarser, and lighter. These traits provide significant pore space allowing air and plant roots to move freely through the soil. But, at the same time, this excessive space does not hold nutrients or water very well, causing them to drain through the soil very quickly (Ball, 1997).

The most advantageous soil texture is therefore somewhere in between clays and sands – providing particles coarse enough to allow sufficient air movement, yet fine enough to retain essential moisture and nutrients. Loamy soils have these characteristics, allowing them to hold moisture and nutrients while providing proper drainage. As mentioned previously, soils in South Carolina's upstate are not loamy and therefore must be amended if the optimum characteristics for plant growth are desired. With the addition of compost, mediocre clay and sand soils are better able to circulate air and sustain proper levels of moisture and nutrients (Ball, 1997).

Increased Microbial Activity

Compost contains a multitude of microorganisms at every stage of its production, responsible for the decomposition of organic matter into humus. When compared to fertile soils, the microbial populations in mature compost are vastly higher (Table 2.1) (U.S. EPA, 1998). Therefore, when mature compost is added to soil, its microbes play an extremely important role in plant growth. Some of these microbial communities are responsible for accelerating the conversion of nitrogen, phosphorous, and other nutrients from the soil particles into accessible forms that can be utilized by plants, while other communities of bacteria protect plant health by attacking disease pathogens in the soil (Ball, 1997).

Table 2.1

Microbial Populations in Soil and Mature Yard Trimmings Compost

Material	Bacteria (10^6 per gram dry weight)	Fungi (10^3 per gram dry weight)
Fertile Soil	6 to 46	9 to 46
Mature Compost	417	155

(Adapted from U.S. EPA, 1998)

Temperature and Weed Control

Although used primarily as a soil amendment, compost can also be used in other applications. One such application is as a mulch to inhibit weed growth. And, because compost produced from municipal facilities is managed to maintain temperature high

enough to kill any weed seeds in the incoming feedstock, no additional weeds should result from the application of cured compost (Ball, 1997).

Another application of compost is to buffer existing soil against extreme changes in temperature. If, for example, the soil temperature exceeds 85°F, root growth will significantly diminish. Conversely, if the soil drops below 65°F, the root systems of most plants will not grow. Because soil temperature is important to the healthy growth of plants, adding rich compost on top of existing soil in the summer will insulate the soil against the sun's heat, keeping temperatures as much as 15°F cooler. On the other hand, if frigid conditions exist, mixing compost into the top layers of the soil will serve to darken the soil, absorbing heat that helps reduce stress on trees and plants and encourages growth earlier in the season (Ball, 1997).

Compost Uses for Trees and Shrubs

Preserving the good health of trees and shrubs is another way in which to utilize compost. Incorporating compost around a tree's dripline – the area below the edge of the canopy – will condition the soil for two to three years. This practice not only provides vital nutrients that aids in proper growth, but it also reduces competition from the surrounding lawn for moisture and nutrients. And, because compost contains disease-suppressing organisms, it is also useful for treating wounds on trees. A tree with damaged bark is normally exposed to infection, but compost applied directly to the damaged area guards against infectious organisms while allowing plant tissues to regenerate (Ball, 1997).

Land Reclamation

Land may become vacant, neglected, or even contaminated as a consequence of human activities, possibly posing a risk to human health and the environment. Within the past several years, studies have indicated that the use of compost can provide a solution to reclaim lands by mitigating environmental risks and enhancing visual appearances. For instance, hydrocarbons have been found to degrade rapidly in the active compost process, while the addition of mature compost to contaminated soil not only increases the degradation of organic pollutants, but also improves the establishment and growth of plants (U.S. EPA, 1998).

Landfill Cover

Not only can compost serve as a traditional landfill cover to ward off vectors, but recent studies have indicated that using compost as a landfill cover can decrease landfill methane emissions by providing a suitable environment for the bacteria responsible for methane degradation (i.e. methanotrophs). Partnered with Waste Management, Inc., the U.S. EPA has used pilot tests to demonstrate that compost covers can reduce landfill methane emissions by as much as 100 percent (U.S. EPA 2002b). These compost covers offer a low-cost control measure for methane emissions, especially for smaller landfills where landfill gas-to-energy initiatives are not economically feasible. This is very promising, given that landfill methane emissions constitute the largest source of anthropogenic methane emissions in the United States (U.S. EPA, 2002b).

CHAPTER 3

MICROORGANISMS PRESENT DURING VARIOUS COMPOSTING PHASES

Under optimal conditions, the composting process is defined by three distinct phases. These phases are characterized by the temperature range at which each phase operates. The first phase is the mesophilic, or moderate-temperature phase, operating between temperatures of 68 to 104° F (20 to 40° C) (Trautmann, 1996). The second phase is the thermophilic, or high-temperature phase, operating between temperatures of 104 to 158° F (40 to 70° C) (Trautmann, 1996). The final phase takes place after biodegradation has occurred, allowing the remaining material to cool down and mature. This phase can last for several months (Trautmann, 1996).

Different microbial communities prevail during each distinct phase of composting. Not surprisingly, the initial phase of composting is carried out by mesophilic microorganisms. The heat these organisms produce through metabolizing the organic material consequently produces a marked increase in overall compost temperature. This rise in temperature segues into the second phase where thermophilic microorganisms continue the decomposition process. During this phase, microorganisms break down more complex matter such as cellulose and hemicellulose, the main structural constituents in plant material. Once nutrients are depleted and the activity of thermophilic microorganisms decreases, temperatures reduce and mesophilic microorganisms once again predominate. Hence, an analysis of the quantity and type of

microorganisms found throughout the composting process is an indicator as to the state of compost maturity (Jimenez and Garcia, 1989).

In general, however, microorganisms involved in composting operations can be divided into two main categories: bacteria and fungi (Trautmann, 1996).

Bacteria

Bacteria are the smallest living organisms, but their enormous numbers allow them to have a profound effect on their surrounding environment. Composting operations are no exception, where bacteria constitute the largest population of microorganisms in the composting process and subsequently are the primary degraders of the system (Khalil *et al.*, 2001). According to Trautmann (1996), bacteria make up 80 to 90 percent of the billions of microorganisms found in a single gram of compost. Their vast numbers, coupled with their diverse metabolic routes and ability to adapt to their environment allow them to biodegrade a variety of organic materials.

As previously mentioned, mesophilic bacteria predominate at temperatures below 104° F (40° C) (Trautmann, 1996). Above this temperature, mesophilic populations rapidly decline and thermophilic bacteria take over. According to Strom (1985), the microbial populations during this phase of composting are dominated by the genus *Bacillus*. The diversity of bacilli species is fairly abundant at moderate thermophilic temperatures, but begins to decrease sharply at 140° F (60° C) (Trautmann, 1996). When conditions in the environment become undesirable, bacilli can survive by forming spores that are highly resistant to stressors such as temperature and lack of moisture and nutrients (Trautmann, 1996).

During the curing phase of composting, filamentous bacteria called actinomycetes are the principal type of bacteria present (Herrmann and Shann, 1996). Actinomycetes are responsible for the earthy smell characteristic of compost and other humic materials. Like other bacteria, actinomycetes lack a true nucleus, but they form filamentous bodies similar to that of eukaryotic fungi. The enzymes associated with this group of bacteria are essential to the further biodegradation of complex organic compounds (Trautmann, 1996).

Fungi

Fungi, to include molds and yeasts, can be either multi-cellular, filamentous, or single-celled organisms. Fungi work in concert with bacteria during biodegradation of organic matter, decomposing much of the complex matter within a system, thus enabling bacteria to further the decomposition process (Trautmann, 1996). According to Herrmann and Shann (1996), fungal communities are active in both the mesophilic and final stages of the composting process. However, fungal species can survive during the harsh thermophilic phase, living on the cooler outer layers of the compost matter when temperatures are highest (Trautmann, 1996).

CHAPTER 4

PHYSICAL PARAMETERS AND THEIR EFFECTS

Composting is a complex biological process, the success of which hinges on many interrelated physical parameters. These parameters include, but are not limited to, particle size, temperature, pH, moisture and oxygen content, and the ratio of carbon to nitrogen in the system. Variations in these parameters can have either positive or detrimental effects on the overall biodegradation process. The following is a description of the characteristics fundamental to successful composting operations, with a brief summary of ideal conditions, as well as the effects on the biodegradation process under non-ideal conditions.

Carbon to Nitrogen Ratio

According to Richard (1996a), the carbon to nitrogen ratio in composting processes is the most important parameter since one of the two compounds typically acts as the limiting nutrient, or substrate, for the system. Carbon serves as the primary source of energy for biosynthesis, while nitrogen is important in microbial systems, as it is contained in proteins which constitute over half of a cell's mass by dry weight.

An analysis of soil microorganisms revealed that they contain approximately 50 percent carbon and 5 percent nitrogen by dry weight (Ro *et al.*, 1998). Assuming that one-half to two-thirds of the carbon used by a cell is converted to carbon dioxide, with the remaining fraction being utilized for cell mass, the carbon to nitrogen ratio required for optimum biological activity lies between the range of 20:1 to 35:1 (Ro *et al.*, 1998).

Grass clippings have a C/N ratio of approximately 20, while fallen leaves can have a C/N ratio from 40 to 80 (Fogarty and Tuovinen, 1991). While grass clippings are on the lower threshold for efficient biodegradation, these ratios may need to be altered to allow for variations in biological activity (Richard, 1996a).

If the carbon to nitrogen ratio is excessive, meaning nitrogen is present in low levels and therefore limiting (e.g. leaves), the substrate stabilization rate will be decreased. This will lead to smaller numbers of microorganisms and an increased time to incorporate the available carbon in the cell. Conversely, if the carbon to nitrogen ratio is low (e.g. grass clippings), nitrogen is abundant and is released from the system mainly as ammonia gas, which may become toxic to the microbial population, cause odors, or raise the system pH (Ro *et al.*, 1998; Richard, 1996a). This relationship was illustrated in a study conducted to determine the influence of the carbon to nitrogen ratio during the composting of straw (Eiland *et al.*, 2001). A slurry of pig manure was then added as a nitrogen source to vary the carbon to nitrogen ratio over a range of 11 to 54. As expected, straw composted with high carbon to nitrogen ratios (nitrogen limited) resulted in low levels of microbial biomass with subsequent low rates of decomposition. Straw composted with low carbon to nitrogen ratios resulted in the converse (Eiland *et al.*, 2001).

Carbon and nitrogen can be manipulated with the help of additives to allow for the optimum ratio. For example, saw dust can be added to composting systems in order to raise the carbon to nitrogen ratio, while substances high in nitrogen, such as manure, sewage sludge, and urea can be added to lower the carbon to nitrogen ratio (Richard, 1996a).

Oxygen Requirements

Since the majority of composting processes operate under aerobic conditions, including yard waste applications, it is essential that microorganisms associated with aerobic composting receive adequate oxygen in order to metabolize and carry out the biodegradation process. The stoichiometric oxygen requirement can be estimated, presuming that all organic carbon is converted to carbon dioxide during the biodegradation process. Given the extended residence time of the composting process, during which endogenous decay is significant, ignoring cell synthesis is a reasonable assumption. Therefore, assuming the material to be composted is a proteinaceous, fully biodegradable substance, the stoichiometric reaction can be expressed as:

$$C_{16}H_{24}O_5N_4 + 16.5\ O_2 \rightarrow 16\ CO_2 + 6\ H_2O + 4\ NH_3 + \text{Heat}$$

The oxygen requirement in this particular case can be calculated by assuming that 80 percent of the proteinaceous material will be biodegraded by the microorganisms during the composting process:

$$(0.80)(16.5 \text{ moles } O_2)(32 \text{ grams } O_2/\text{mole}) = 422.4 \text{ grams } O_2 \qquad (4.1)$$

Dividing the oxygen requirement by the molecular weight of the organic substance to be composted yields 1.2 grams of O_2 required for every gram of organic substance composted. In general, approximately 1 to 4 grams of oxygen are required for every gram of organic substance composted. Furthermore, the oxygen requirement for mixed substrates can be calculated by taking the sum of their individual oxygen requirements (Ro *et al.*, 1998).

Inadequate levels of oxygen will cause a decline in aerobic microorganism populations. Without oxygen, biodegradation will still occur, however it will be

accomplished through the actions of anaerobic microorganisms. This reduction in organic matter by fermentative processes not only slows down the overall rate of biodegradation, but is accompanied by strong, disagreeable odors and is an unwanted turn of events for aerobic composting operations (Richard, 1996a). Buckner (2002) determined that low odor concentrations in yard waste composting are normally achieved only in windrows that maintain a mean oxygen concentration of 10 percent or greater.

Moisture Content

Moisture is a vital ingredient to successful composting operations. According to Richard (1996a), "moisture is essential to the decomposition process, as most of the decomposition occurs in the thin liquid films on the surfaces of particles." Moisture also acts as a solvent for nutrients, making substrates soluble for incorporation into the cell. However, oxygen can become the limiting nutrient in aqueous aerobic environments due to its low solubility in water. For this specific reason, too much water can negatively impact the microbial processes in a composting system by filling the space between particles and severely limiting the transfer of oxygen to microorganisms. Since many composting operations (e.g. yard waste applications) rely on active aerobic processes, it is imperative that composting systems contain a proper fraction of air to allow for sufficient oxygen diffusion through the system (Ro *et al.*, 1998).

The recommended moisture content for optimum biodegradation ranges between 50 and 60 percent. Above this amount, excess water infiltrates the air space between particles, hindering the diffusion of oxygen through the system. Below this recommended amount, moisture is not available in sufficient quantities to support microbial growth, reducing process efficiency (Hamoda *et al.*, 1998).

While electronic devices are available to precisely measure the moisture content of compost, a sage and experienced technician can estimate the moisture content of compost piles with a fair amount of accuracy using the "squeeze test." With this method, a handful of compost is obtained and firmly squeezed. If your hand is dry and the material is crumbly and doesn't remain together, then the moisture content of the material is 40 percent or less (SC DHEC, 2002b). If the material sticks together and your hand is moist, then the compost contains approximately 50 percent moisture. If the material sticks together and drips after being squeezed and your hand is wet, then the moisture content of the compost is approximately 60 percent or greater (SC DHEC, 2002b).

Particle Size

Particle size is closely related to moisture content with regard to its effects on microbial populations in composting operations. As previously mentioned, the majority of decomposition in composting takes place on the surface of particles in their associated liquid films. Because of this fact, smaller particles with larger surface areas relative to their volume exhibit enhanced microbial activity, increasing the biochemical reaction rate during composting (Tchobanoglous *et al.*, 1993). However, while smaller particle sizes are a benefit to increased microbial reactions, they reduce the amount of air space in the compost environment, reducing the amount of available oxygen as well as the amount of space available for substrate transport to the microorganisms.

A balance in particle size must be achieved so that the composition contains particles small enough to generate sufficient microbial activity, while at the same time be large enough to allow for efficient oxygen and substrate transport. Subsequently, particle sizes between 0.5 to 2 inches are generally considered appropriate for use in composting

operations to provide adequate surface area and pore space to initiate efficient microbial activity (Ro *et al.*, 1998). Particle size is routinely managed through the use of shredders and mixing devices to ensure a homogenous size of particles within the compost.

Temperature

Temperature in composting operations fluctuates in response to microbial activity. The greater the rate of biodegradation, the greater the temperature generated. In other words, the temperature rise in compost processes is a direct result of the exothermic reactions associated with respiratory metabolism of microorganisms (Tchobanoglous *et al.*, 1993). Increased temperature in municipal solid waste applications not only creates the desired mesophilic conditions, 68 to 104° F (20 to 40° C), and thermophilic conditions, 104 to 158° F (40 to 70° C), but it also serves a very important function to sanitize the compost, removing many disease-causing pathogens (Ro *et al.*, 1998). Upon consumption of readily-available substrate nutrients such as lipids, proteins, sugars, and starches, microbial activity will decrease. Consequently, temperatures in the system will decrease to levels below 140° F (60° C), allowing fungi and actinomycetes to consume cellulose and lignin constituents remaining in the substrate (Ro *et al.*, 1998).

Although higher temperatures in composting are very beneficial, temperatures above 158° F (70° C) will not only inactivate the microorganisms related with composting, but will also denature their associated enzymes, subsequently halting the composting process (Fogarty and Tuovinen, 1991). Fortunately, temperatures can be regulated in compost systems through monitoring and controlling the airflow through aeration (Tchobanoglous *et al.*, 1993). Aeration techniques such as mechanical mixing and forced aeration are discussed further in Chapter 5.

pH

Control of the system pH is another important parameter to consider in order to produce efficient and active microbial populations during composting operations. As with temperature, the value of pH varies as a function of time during composting, ranging from approximately 5 to 8.5 for typical municipal solid waste composting applications (Tchobanoglous *et al.*, 1993). Although there is some variation in the pH of a composting system, Ro *et al.* (1998) state that the pH of a composting operation must be near neutral (pH of 7).

Microbial growth and subsequent compost degradation is inhibited at pH values less than 3 or greater than 11. At low pH extremes, the environment is strongly acidic and the composting process will be halted by the leaching of toxic chemicals such as aluminum, copper, and zinc from minerals and substrates. At high pH extremes, the environment is strongly basic and the composting process experiences the production of unionized ammonia in addition to the precipitation of elements such as calcium and magnesium essential to microbial growth (Ro *et al.*, 1998).

As with other parameters, the pH of a compost system can be manipulated. This is accomplished through the use of co-substrates or other pH-adjusting media such as lime and baking soda. For example, wood wastes and sludges formed as a result of paper manufacturing tend to have lower pH values of around 5 (Ro *et al.*, 1998). Utilizing an ammonia-releasing substrate such as urine will not only help to raise the pH closer to neutrality, but, because wood and its associated wastes have a relatively high carbon to nitrogen ratio, the addition of such a substrate will also serve to provide much needed nitrogen to the microorganisms in the compost (Ro *et al.*, 1998).

CHAPTER 5

LEVELS OF TECHNOLOGY

Four levels of technology exist for conventional windrow composting – minimal, low, intermediate, and high. The definitions for these technologies were developed by Peter Strom and Melvin Finstein as part of a study on large-scale leaf composting for New Jersey municipalities. The level of technology refers to the time it takes to reach ideal conditions for composting. As a rule of thumb, the lower the level of technology, the greater the requirement for space and composting time, but the more cost effective the process (Strom and Finstein, 1989).

Minimal Technology

The minimal level of technology is suitable if: (1) a low-cost approach is desired; (2) the proposed compost area is well isolated from surrounding residents; and/or (3) time is of little concern. This process forms large windrows (approximately 12 feet high by 24 feet wide) turned once per year using a front-end loader (Strom and Finstein, 1989). With only annual turnings, much of the windrow's interior remains anaerobic, making it impossible to achieve the conditions necessary for rapid biodegradation. Subsequently, two to three years is normally required for the compost to completely stabilize (Tchobanoglous *et al.*, 1993). In addition, anaerobic conditions in the center of the windrow will create odors during the first year and will produce exceptionally foul odors as a result of the first turning. These odors will require an extensive buffer zone in excess of one-quarter mile to protect surrounding residents from exposure. The odors,

however, should be greatly diminished by the second turning (Strom and Finstein, 1989). With manpower and equipment needed only a few days per year, minimal technology requires very little attention. This equates to a relatively hassle-free and inexpensive operation. However, because of the pungent odors produced as a result of anaerobic processes, a very large total area is essential for effective operations, although only a small portion of it is actually used for the composting.

Low Technology

As with minimal technology, low-technology composting is relatively inexpensive, requiring a front-end loader as the sole piece of equipment. This process forms smaller windrows, approximately 6 feet high by 12 to 14 feet wide, which are turned three to five times per year (Tchobanoglous *et al.*, 1993). The smaller windrow size helps to balance the need to maintain sufficient heat and concurrently allows for adequate oxygen diffusion through the pile, while the more frequent turning helps to reduce odors. When the first surge of microbial activity decreases after approximately one month, two windrows can be combined into one. After 10 to 11 months of composting, the pile is then moved to the site perimeter to allow for final curing, thus freeing the original location to accept new organic material. Using this approach, thoroughly cured compost can be produce in 16 to 18 months (Strom and Finstein, 1989).

Although the smaller windrows used in this process require a larger area when compared to the minimal technology, the size of the total area is smaller because of the reduced buffer requirement associated with less odor. According to Strom and Finstein (1989), slight odors may be produced early on in the biodegradation process and especially during the first turning, but these odors are typically not detected more than a

few yards away from the windrows. And, as mentioned earlier, costs are still low, as only three to four front-end loader operations are required from initial windrow formation to final curing.

Intermediate Technology

The intermediate-level approach to composting requires that windrows be turned more frequently. The more frequent turning will accelerate the biodegradation process by providing improved aeration and increased particle size reduction. Due to the increased biological activity, turning must continue on a regular basis to avoid acidic and anaerobic conditions that lead to the formation of odors. Mixing is accomplished twice per week at the onset, but then can be curtailed to one turning per week. To ensure windrows are mixed as often as necessary, oxygen content and temperature within the windrows should be closely monitored in order to maintain oxygen levels above five percent and temperatures below 60° C (140° F) (Strom and Finstein, 1989). Following this approach, fully cured compost can be produced in approximately four to six months (Tchobanoglous *et al.*, 1993).

With the frequent mixing required from the intermediate-level approach, turning with a front-end loader becomes impractical. The process would prove to be too time consuming, too high in labor and equipment costs, and result in inadequate size reduction. Consequently, specialized windrow turning machines should be used. Numerous turning machines are available commercially and can range from tractor-mounted devices that drive along each side of the windrow turning half of it at a time, to elaborate machines that straddle the entire windrow (Strom and Finstein, 1989).

The main advantage to the intermediate technology is the reduced time it takes to achieve mature compost. Disadvantages include the upfront expense of purchasing a dedicated windrow turning machine, as well as the associated manpower to monitor the windrows and operate the machinery. And, in many cases, the dimensions of windrows are limited by the size of the turning machines, causing this approach to require more land than the low-level technology. Additionally, more site preparation may also be required, as specialized turning machinery may require a better-graded surface for efficient operation (Strom and Finstein, 1989).

High Technology

High-level technology achieves the maximum rate of decomposition for windrow composting by maintaining favorable levels of oxygenation and temperature. This process achieves these optimal conditions through the use of forced aeration. Aeration can be either positive, blowing up through the pile; or negative, drawing air down into the pile. While both methods are effective at maintaining proper conditions, negative aeration has the added capability of exhausting the processed air through odor control devices (Pierce County, Washington, 2003). However, the U.S. EPA (1994) states that "positive pressure can be more effective at cooling the pile and is preferred when warm temperatures are a major concern," which is clearly applicable for South Carolina.

The most common type of forced aeration approach is the static pile method (Tchobanoglous *et al.*, 1993). The blower associated with these systems is controlled by a temperature feedback system. If the temperature of the windrow exceeds a preset value, the blower is automatically activated to cool the pile. This strategy not only ensures that temperatures are maintained at proper levels, but it also maintains well-

oxygenated conditions for proper aerobic biodegradation. This forced aeration technique is used for a period of approximately two to ten weeks, at which time the blowers are deactivated and the piles are periodically turned until the compost has fully matured (Strom and Finstein, 1989).

One advantage of the high-technology approach is that, unlike low and intermediate technologies, large windrows can be formed. According to Tchobanoglous *et al.* (1993), high technology windrows can be formed eight to ten feet high and as much as 16 to 20 feet wide. Although these piles rival the size of minimal-technology windrows, extensive anaerobic conditions do not develop because good aeration is maintained. And, as a result of the increased rate of biodegradation, complete composting can occur on the order of three to four months (Tchobanoglous *et al.*, 1993). However, odors may be released during initial windrow formation and start up, so a moderate size buffer zone is still required. Additionally, when compared to lower technology composting, aerated piles require supplementary site infrastructure such as electricity, fans, manifolds, ducts, pipes, controllers, and additional labor for installation (*BioCycle*, 1999a). Subsequently, these improvements will increase both the initial costs and sustained costs required to operate such a facility (Strom and Finstein, 1989). Appendix A provides additional information on the capital and operating costs associated with a high level technology facility.

In-Vessel Technology

In addition to the four previously mentioned composting technologies, Tchobanoglous *et al.* (1993) describe a fifth level of technology that can be used for composting organic wastes: high-level in-vessel. In-vessel composting systems are

proprietary and a number of these systems are available commercially. These systems differ from windrow composting in that waste is composted within an enclosed container. In-vessel composting times can vary widely from 8 hours to 20 days, depending on the particular process as well as the composition of the feedstock (e.g., yard waste, biosolids, etc.). Once the initial processing is complete, further curing takes place in open windrows for an additional six to eight weeks, making these systems the fastest method to obtain a finished product. In-vessel systems incorporate aeration and mixing and offer many advantages over conventional windrow composting. In addition to significantly reduced maturation rates, this technology also decreases area requirements, lowers labor expenses, and increases process and odor control (Tchobanoglous *et al.*, 1993).

Table 5.1

Summary of Technology Levels[a]

	Minimal	Low	Intermediate	High	In-Vessel
Windrow Height, ft	10-12	5-7	5-8	8-10	See Note *b*
Windrow Width, ft	20-24	12-14	12-18	16-20	See Note *b*
Turning Frequency	1/year	3-5/year	Weekly	See Note *d*	See Note *b*
Time to Product, mos	24-36	14-18	4-6	3-4	2-2.5[c]

[a]Adapted in part from Tchobanoglous *et al.*, 1993.
[b]In-vessel systems are mechanical, proprietary systems unlike conventional windrows.
[c]In-vessel composting times vary from 8 hours to 20 days, with further curing for 6-8 weeks.
[d]Forced aeration is used for 2-10 weeks.

Choosing an Appropriate Level of Technology

Several factors should be taken into account when selecting which type of technology to use. How much money is the municipality willing to spend to implement and sustain a successful composting program? What is the composition of the feedstock? How much land is available for the proposed composting operation? The type of equipment already owned by the municipality and available manpower are also important considerations when deciding what technology to implement (Daniel and Smith, 1992).

Although popularity for high technology and in-vessel systems is on the rise, they are inherently expensive to build and operate. Consequently, these technologies are not warranted for yard-waste composting, and are typically reserved for the composting of biosolids, food wastes, and other putrescent solid wastes (Dickson and Richard, 1989; Strom and Finstein, 1994; and May and Simpson, 2003). Furthermore, the elevated occurrence of anaerobic conditions and rancid odors, coupled with the excessive processing times related to minimal technology facilities make this approach unappealing as well. As a consequence, this research will focus on low and intermediate technologies as practical options to adequately meet the composting needs of Anderson County.

CHAPTER 6

COMPOSTING EQUIPMENT

Specialized equipment is required in composting operations to properly handle materials prior to, during, and after the active phase of composting. However, the type of equipment selected will vary substantially depending on the size of the facility and level of technology utilized. Front-end loaders are the minimum equipment required for a minimal-technology operation, while grinders and screeners are needed if a higher-quality end product is desired. Additionally, monitoring equipment such as temperature probes and pH meters will be necessary to accurately supervise the composting process. Accordingly, this section briefly discusses the major types of equipment used in composting applications and presents accompanying cost estimates.

Front-End Loaders

From transporting yard waste to forming windrows to towing windrow mixing machinery, front-end loaders are a versatile and necessary addition to any municipal composting operation. According to May and Simpson (2003), either track loaders or wheel loaders may be used in composting operations. Track loaders are best if composting will take place in loose or muddy soils. Wheel loaders, on the other hand, offer more flexibility, in that they are more easily maneuvered and cause less compaction and damage to road surfaces. Both types of loaders are typically equipped with diesel engines and can have a wide range of bucket sizes, but most front-end loaders suitable for municipal composting operations will range between $90,000 and $150,000.

Grinders

Grinders are frequently used for shredding woody materials destined for composting. The use of grinders is an important step in materials preparation, as it reduces the volume of the incoming yard waste, thus reducing the area required for windrow formation (*BioCycle,* 1989a). As with front-end loaders, several types of grinders exist. The two most common varieties are tub grinders and horizontal grinders. A tub grinder is a hammer mill with a rotating tub-like hopper, which subsequently feeds yard waste into the hammer chamber. A horizontal grinder also uses a hammer mill system to shear incoming material, but it uses a horizontal conveyor rather than a rotating tub, which allows for virtually no limitations on the length of material it can process (Rynk, 2000a). Once the material has been reduced in size inside the hammer chamber, it is then forced through a screen and onto a conveyor belt that discharges the shredded material into piles or onto a transfer vehicle (May and Simpson, 2003).

Grinders are hard-working machines, available in several models with differing capabilities, but most are very adept at grinding vast amounts of dry wood and brush. Larger, heavy-duty machines can process 50 to 125 cubic yards (10 to 25 tons) per hour, with pieces of wood up to 12 inches in diameter (May and Simpson, 2003).

Without question, the purchase of a grinder is the single largest equipment investment for a compost facility. There are numerous manufacturers and models, with prices typically ranging between $200,000 and $300,000.

Compost Turners

Compost turners, or windrow turners, are designed specifically for windrow turning and aeration and can range in price from approximately $20,000 to over

$250,000. Most turners employ a series of tines attached to a horizontal drum (*BioCycle,* 1989a). The turner shreds, mixes, and aerates the compost before reforming the pile into a trapezoidal shape as it moves along the windrow (Dickson and Richard, 1989).

Larger compost turners are self-propelled, while smaller units require the assistance of a tractor, loader, or other prime mover. Additionally, larger turners straddle the windrow, turning the entire pile at once, whereas smaller units operate by turning only one side of the windrow at a time, thus requiring two passes for each pile (May and Simpson, 2003). Some models can even be fitted with water lines to irrigate windrows as they are turned (Dickson and Richard, 1989).

Screeners

As mentioned earlier, grinders are extremely effective at reducing the size of woody material prior to windrow formation. However, the carbon in the wood is relatively unavailable to the microbial community, allowing only partial biodegradation of the wood chips during the compost process. And, because the compost market is driven by the quality of the end product, any compost producer wishing to create commercially viable compost must screen the cured compost as a final step to improve its physical characteristics. This screening yields a more uniform, debris-free end product, while separating the wood chips (i.e. mulch), which are highly marketable in their own right (Strom and Finstein, 1994).

There are a variety of screening devices that can be utilized for composting operations including shaker, vibrating, and scalper screens, but probably the most common type of screen used is the trommel screen (Dickson and Richard, 1989). These machines range in price from approximately $50,000 to over $200,000.

In trommel screens, the compost to be screened is typically loaded into a hopper using a front-end loader. The material is then moved via conveyor and deposited in a long, rotating, cylindrical screen that is placed on an angle so that materials readily flow through. Compost materials that are smaller than the screen fall through, while larger materials continue through the cylinder. A brush is attached to the outside of the screen to dislodge materials as the trommel screen rotates, thus preventing clogging of the screen (U.S. EPA, 1994).

Water Trucks

In order to maintain adequate levels of moisture within windrows, a municipality may decide to incorporate water lines into the facility design. If, however, the integration of a utility infrastructure is cost prohibitive, the use of a water truck is the likely alternative. Water trucks come in a wide range of tank sizes, and can be configured with discharge nozzles on the front, side, and rear of the truck. Additionally, water trucks are typically outfitted to intake water from various sources (e.g., hydrants and ponds). Water trucks suitable for composting operations are in abundance on the used market and typically range between $25,000 and $60,000. In addition, the used market may also contain viable, less expensive grinders, windrow turners, and screeners, thereby reducing the capital expenses associated with these pieces of composting equipment as well.

Monitoring Equipment

In addition to specialized machinery such as compost turners and trommel screens, additional equipment is necessary to ensure good process management. From temperature probes to maturity testing kits, a few of the more common pieces of monitoring equipment are described below.

Temperature Probes

Temperature is one of the key indicators in composting. Maintaining a sufficient windrow temperature is also extremely important in the destruction of pathogens (this will be discussed further in Chapter 11). Accordingly, windrow temperatures should be monitored closely using temperature probes to gauge how well the overall process is working and how far along the decomposition has progressed. The average cost for a suitable, long-stemmed temperature probe will range from $75 to $100.

Oxygen Sensors

Oxygen sensors should be employed to determine the level of compost aeration within a windrow. Frequent monitoring will identify when mechanical mixing is required, thus decreasing the incidence of anaerobic conditions and odors. Oxygen sensors are based on a volumetric measurement and are typically priced around $1,000.

Wind Monitoring Devices

Wind monitoring devices are not required for compost operations, but are very helpful in timing windrow turnings to coincide with favorable wind conditions that avoid nearby residences and other sensitive land uses. Some wind monitoring devices include accessories such as rain collectors and ambient temperature gauges. Depending on the manufacturer and selected options, the cost of a simple weather station will typically range between $500 and $1,000.

Maturity Test Kits

A maturity test kit should be employed to give facility operators a quantitative approach to determine when yard waste has completed the active composting process and

is ready to prepare for final processing. One widely recognized test is the Solvita Test Kit. The Solvita kit measures the carbon dioxide respiration and ammonia volatility of a given sample of compost. These two traits offer important information to compost quality and used together can provide an estimate to the general condition of a given compost sample (Woods End Research Laboratory, 2003).

The Solvita test rates compost maturity on an index scale of 1 to 8, with 8 signifying the highest level of maturity. The higher the level of maturity, the more resistant the compost is to further decomposition and free of harmful compounds such as ammonia and organic acids which can prove harmful to plant growth. The cost to perform the Solvita test is $12 per kit, with each kit able to analyze a single sample (Woods End Research Laboratory, 2003).

Although maturity tests like the Solvita test are beneficial in providing an estimated measure of compost maturity, they do not indicate the presence of harmful contaminants such as pesticides and herbicides. Therefore, municipalities preparing to implement a yard waste composting operation should plan to have mature compost analyzed by a certified laboratory to ensure it does not contain harmful constituents capable of producing detrimental effects. Chapter 10 discusses appropriate testing methods in greater detail.

CHAPTER 7

SITE SELECTION CONSIDERATIONS

The siting of a compost facility is of fundamental importance in the initial stages of facility planning and involves the consideration of numerous factors. Issues that must be addressed include land requirements, water supply and control, building and equipment needs, and environmental and safety concerns. This section will discuss these essential concerns while highlighting some of the important South Carolina regulations that govern the siting of a municipal compost facility.

Location

BioCycle (1989b) recommends a centralized area with access over hard-surface, non-residential roads as the preferred location for a municipal yard waste compost facility, identifying areas adjacent to cemeteries, airport runway buffers, golf courses, and landfills as suitable locations.

Area Requirements

The land area required for composting operations is determined by factoring in the volume of incoming yard waste, the dimensions of windrows used, and the estimated time required to complete the composting process (Dickson and Richard, 1989). This land requirement can be approximated for windrow systems by estimating one acre for every 4,000 to 5,000 cubic yards of loose incoming yard waste (Daniel and Smith, 1992), and is based upon the composting of leaves with the low-level technology, which requires approximately one year to generate a viable product (Strom, 2003). In addition,

BioCycle (1989b) states that a five-acre site should be adequate for composting 20,000 cubic yards of incoming yard waste, which agrees with the 4,000 cubic yards per acre estimate proposed by Daniel and Smith (1992). This estimate not only accounts for the sizing of windrow pads, but also accommodates the staging, curing, and post-processing activities (May and Simpson, 2003).

Slope and Grading

South Carolina recommends the composting site be graded to maintain a slope of approximately two percent (SC DHEC, 2002a). Anything less will produce ponding of runoff and leachate, which can lead to exceedingly high moisture levels within windrows and contribute to an unwanted breeding ground for mosquitoes. A steep slope, on the other hand, is unacceptable because it creates problems with erosion, vehicular access, and equipment operation (Strom and Finstein, 1994).

In order to optimize site selection and grading efficiency, drainage characteristics of the site should be identified from U.S. Geological Survey topographic maps (Strom and Finstein, 1994). Once the site is properly graded and ready to receive yard waste, windrows should be constructed up and down the slope rather than across it. This will allow runoff and leachate to move down gradient between windrows instead of across subsequent piles (South Carolina Code of Regulations, 2002).

Water Table

A compost facility located in an area with a high water table is undesirable, as it increases the chance of site flooding and can lead to extensive anaerobic conditions if windrows are left to sit in standing water. A deeper water table is preferable, since it lessens the chance of groundwater pollution by providing greater filtration of leachate

(*Biocycle*, 1989b). South Carolina regulations require the bottom elevation of the compost pad and storage areas be a minimum of two feet above the seasonal high water table as it exists prior to construction (South Carolina Code of Regulations, 2002).

Flood Plain

The South Carolina Code of Regulations (2002) allows a compost facility to be located in a flood plain, but the facility must not restrict the flow of the 100-year flood. However, siting of a new facility in or near a flood plain would be ill-advised. Similar to conditions caused by a high water table, allowing windrows to remain in standing water generated from a flood can quickly induce anaerobic conditions. Or worse, windrows could possibly wash away.

Water Quality

It is imperative that composting operations not affect the water quality of surrounding ground and surface waters. The South Carolina Code of Regulations (2002) requires appropriate site design and management to adequately protect ground and surface waters from contamination. As mentioned above, the compost area must maintain a 2-foot separation from any groundwater. In addition, the compost facility cannot be closer than 200 feet from streams and rivers, nor can it be closer than 100 feet from all drinking water wells.

If the active composting area is unpaved, the predominant approach to manage leachate and runoff is to create a grass filter strip down gradient from the compost area that extends the entire width of the pad. May and Simpson (2003) recommend a filter strip long enough to contain the runoff generated from the two-year, 24-hour rainfall event for the facility's location. Grass species such as fescue and reed canary are

appropriate, and should be harvested regularly to remove the nutrients they absorb. This filter strip should not be disturbed by vehicular traffic or heavy machinery (May and Simpson, 2003).

If, however, paved surfaces are used, a more substantial collection and treatment system will be necessary to handle the larger volumes of runoff and leachate produced, thus protecting nearby surface waters. These systems can include trenches and stone dams for direction and collection of runoff, grassed waterways for filtration of suspended particles, and collection ponds. In addition to designing a sufficient runoff collection system, care should be taken to also minimize the amount of runoff and leachate generated. This can easily be accomplished by ensuring the compost pad is either raised or bermed to prevent run-on (May and Simpson, 2003).

Pavement Options

BioCycle (1999b) jokingly states that "if composters had a genie that could grant them three wishes… having a site with a paved surface would be one of them." Whether it is concrete or asphalt, composting on an improved surface offers many advantages. Facility design is driven by the quality of the end product, and unless a facility's compost is intended for lower-value end uses such as landfill cover, the construction of an improved surface on which to compost is a worthwhile investment (*BioCycle,* 1999c).

Unpaved facilities with a packed earth floor are decidedly cheaper to construct. However, in addition to grading during initial site preparation, annual regrading may be necessary, since such facilities experience considerable problems with mud during periods of heavy rain. This situation creates severe channeling and ponding that prohibits

further use of heavy machinery on and around windrows, significantly delaying the time it takes to produce a viable product.

Improved concrete or asphalt surfaces allow for year round access, have lower maintenance demands, keep dirt and gravel from infiltrating the windrows, and diminish the potential for ponding that can be the source of odors (*BioCycle*, 1999b). Also, a well-designed pad with proper runoff control provides the needed, impervious surface to ensure leachate from windrows does not contaminate surface and ground waters (Epstein and Epstein, 1989). Furthermore, a paved surface may be required if an intermediate-level composting technology is selected, as specialized turning machinery may require a better surface for efficient operation (Strom and Finstein, 1989).

If, however, a fully paved concrete or asphalt surface is considered cost prohibitive, one alternative would be to partially pave the compost pad, allowing heavy equipment to operate on an improved surface while the windrows rest on the unpaved ground. This not only reduces the capital costs associated with paving, but also lessens storm water detention requirements. While economically attractive, this option is not without its apparent disadvantages. As with the non-paved option, care should be taken to ensure that grading of the unpaved windrow footprints is not damaged by front-end loaders during extraction operations. Otherwise, maintenance demands could be increased and compost quality could be reduced through the inadvertent addition of dirt and gravel to the windrows. Additionally, any uneven grading caused by careless equipment operation could increase the potential for ponding with subsequent odors.

A second alternative to a fully paved concrete or asphalt surface is a lime-stabilized pad. Lime-stabilized pads offer a less-expensive solution while creating a fully

paved, impermeable surface with similar properties to concrete. In fact, on a 1.3 acre test site, the total cost for constructing such a pad was one quarter the cost of concrete (*BioCycle*, 1999c). This technique has been used in the past by the military to build runways in rural areas and it works best in clay soils like those abundant in Anderson County, South Carolina (May and Simpson, 2003). The process involves a mixture of quicklime, fly ash, Portland cement, and cement kiln dust to form a hard, dense surface that offers good resistance to liquid penetration (*BioCycle*, 1999d).

Buffer Zones

Buffer zones are required between the active operations of a compost facility and any neighboring land use to reduce potential impacts such as odor, noise, and dust (Strom and Finstein, 1994). The South Carolina Code of Regulations (2002) requires a 50-foot minimum buffer between all property lines and compost pad or storage area, and a 200-foot minimum buffer between compost pad or storage area and residences or dwellings. Additionally, Strom and Finstein (1994) recommend a 1,000-foot minimum buffer from the staging and composting areas if grass clippings will be brought to the site, because of the increased potential for odor problems.

The buffer zone may incorporate an earthen berm to serve as a visual barrier from nearby residences. A berm will also aid in controlling vehicular access and diminish off-site noise levels. Another option is to include plantings and landscaping in the buffer zone. Landscaping will not only help to control vehicular traffic and help to absorb noise from composting activities, but it will also significantly enhance the appearance of the facility, conveying a professional image (Strom and Finstein, 1994).

Site Security

An unsecured compost facility is subject to vandalism, illegal dumping, and unlawful theft of cured compost. Consequently, The South Carolina Code of Regulations (2002) requires that compost facilities "shall be secured by means of gates, chains, berms, fences, or other security measures to prevent unauthorized entry." Fences and gates are the preferred means for controlling entry unless access to the site is limited due to natural geographic barriers (e.g., hills and streams). Appropriate signage such as "Keep Out and "No Dumping" are additional recommended deterrents (*BioCycle*, 1989b). Additionally, facility employees should be on-site during operating hours to monitor incoming yard waste (May and Simpson, 2003).

CHAPTER 8

ODOR CONTROL

Haug (1993) takes a rather tongue-in-cheek approach to discussing odor management. Some of his theorems on the subject include: (1) "Mother Nature never claimed to be odor free;" (2) "what smells okay to you is probably an odor to someone else;" (3) "odor treatment is never 100 percent effective;" and (4) "the worst odor will never occur when you're there." Odors are indeed an unpleasant and unavoidable fact in composting operations. If left unchecked, odors can anger nearby residents, stifle good relations with regulators, and jeopardize the future of a composting facility. Consider the following cases in point from Feinbaum (2000):

- Lake Forest, IL: In the summer of 1994, standing water from grass windrows coupled with high heat and humidity created an odor problem at a yard-trimmings facility. This subsequently prompted concern about the associated adverse health impacts of the facility. The situation escalated to calls for closure of the facility from angry nearby residents.
- North White Plains, NY: In 1997, after three years of odor complaints from nearby residents, the New York State Department of Environmental Conservation gave a composting business five months to remove all materials and vacate its property.
- Seattle, WA: In 1997, Washington's largest composting operation faced negative publicity, a lawsuit from nearby residents, and a $500,000 fine from state regulators over offensive odors.

Although odors are inevitable when operating a compost facility, they are indeed manageable. With proper planning and process management, odors can be minimized and even contained. The following section will focus on ways to effectively control odors including discussion on: (1) the compounds that produce odors; (2) the factors affecting odor generation and the appropriate process management techniques required to minimize odor production; (3) methods used to conceal and contain those odors that are invariably produced; and (4) effective communication with surrounding residents.

Odor-Producing Compounds

All plants excrete odorous compounds on a nearly constant basis, and all starting feedstocks for yard waste composting are derived from plant materials. Consequently, it would stand to reason that these substrates will contain many odorous compounds. Although many starting substrates do not contain odorous compounds of an objectionable nature, the biochemical metabolism that takes place during active decomposition will undoubtedly produce many intermediate compounds that are indeed objectionable (Haug, 1993). These compounds can include hydrogen sulfide, other sulfur-containing organic compounds, fatty acids, and amines, which result from the yard waste becoming anaerobic during the decomposition process. In addition, ammonia can cause odor problems even in aerobic conditions (Glenn, 1990).

Hydrogen Sulfide

Hydrogen sulfide (H_2S) is responsible for the characteristic rotten egg smell. H_2S can be detected at concentrations of only 0.5 parts per billion in air and is produced by two main pathways (Haug, 1993). The first involves the reduction of sulfate (SO_4^{2-}), the most oxidized form of sulfur, to H_2S under anaerobic conditions by sulfate-reducing

bacteria (Madigan *et al.*, 2003). The second pathway for H_2S formation is by the anaerobic decomposition of proteins or other sulfur-containing organics (Haug, 1993).

Other Sulfur-Containing Organic Compounds

As with H_2S, additional sulfur-containing organic compounds are also synthesized by microorganisms (Madigan *et al.*, 2003). Mercaptans, for example, are analogous to alcohols in structure, having the general form R-SH. Like other sulfur-containing organic compounds, mercaptans are distinguished by their offensive odors – in fact, the compound largely responsible for the stench given off by skunks is butyl mercaptan. And, the compound ethyl mercaptan can be distinguished in air at concentrations as low as 0.33 parts per billion by volume (Haug, 1993).

Another group of sulfur-containing organic compounds are the alkyl sulfides. These compounds are the sulfur analog to ethers, with a general formula of R-S-R. Alkyl sulfides are common in nature, responsible for the scents and flavors of plants in the onion and garlic family. Dimethyl sulfide, a specific alkyl sulfide, is the most abundant sulfur-containing organic compound found in nature (Madigan *et al.*, 2003), and can be detected in the air at concentrations of one part per billion (Haug, 1993). Furthermore, dimethyl sulfide produced in anoxic environments can be used as a substrate for some methanogenic bacteria, yielding methane and additional H_2S (Madigan *et al.*, 2003).

Fatty Acids

According to Haug (1993), fatty acids are "relatively long-chained, monocarboxylic acids that occur in nature as constituents of fats, oils, and waxes." These longer chained fatty acids can be hydrolyzed (broken down by the addition of water) into smaller, volatile acids such as butyric, propionic, and acetic acids. In addition to

volatilizing in the atmosphere and producing a distinguishable vinegar smell, acetic acid is readily degradable and can serve as the substrate for methanogenic bacteria under anaerobic conditions, producing an additional source of methane (Haug, 1993).

Ammonia

Ammonia (NH_3) is produced under both aerobic and anaerobic conditions during the deamination of organic nitrogen compounds such as amino acids and proteins (Madigan *et al.*, 2003). As mentioned earlier, any substrate with a low C/N ratio (e.g., grass clippings) will likely release excess nitrogen from the system mainly as ammonia gas (Ro *et al.*, 1998). Fortunately, the recognition threshold for ammonia is relatively high at approximately 47 parts per million in air (Haug, 1993).

Amines

Amines are organic derivatives of ammonia in which one or more hydrogen atom is replaced by an alkyl group. They are formed during the anaerobic decomposition of proteins and amino acids. Amines are found in particular agricultural wastes, such as those from the fish and beet sugar industries, and can have descriptive names such as cadaverine and putrescine because of their characteristically fishy and rotten odors (Haug, 1993).

Whether aerobic or anaerobic conditions govern the composting process, over 80 percent of all unpleasant odors in composting operations are the result of nitrogen and sulfur-bearing compounds (Bader, 2002a). And, as described above, odor control can become very challenging given that some compounds require only a very small number of molecules to produce detectable odors (O'Malley, 2003). Table 8.1 summarizes the

threshold concentrations for some of the more common odors found in composting operations.

Table 8.1

Threshold Concentrations and Boiling Points for Selected Odorous Compounds

Compound	**Recognition Threshold (ppm_v)**	**Boiling Point 1 atm (°C)**
Ammonia	47	-33
Hydrogen Sulfide	0.0047	-62
Methyl Mercaptan	0.0021	-6
Ethylamine	0.8300	17
Ethyl Mercaptan	0.0033	23
Dimethyl Sulfide	0.0010	36

(Adapted from Haug, 1993)

Table 8.1 also illustrates that the boiling points for ammonia, hydrogen sulfide, ethyl mercaptan, and dimethyl sulfide are all much lower than the thermophilic temperatures (40 to 70°C) associated with the active phase of composting. As a result, these compounds will likely volatilize and be released into the atmosphere if they are produced during composting (Haug, 1993).

Odor Index

In 1973, Hellman and Small published a work entitled "Characterization of Odor Properties of 101 Petrochemicals Using Sensory Methods," introducing the concept of Odor Index (OI), which measures the potential of a specific compound to produce odor problems. The OI is a dimensionless value and is defined as:

$$OI = \frac{\text{vapor pressure (ppm}_v\text{)}}{\text{odor recognition threshold (ppm}_v\text{)}}$$

The OI utilizes the vapor pressure of a compound, which measures the potential for the compound to be emitted to the atmosphere, along with the odor recognition threshold, which quantifies the odor strength of a particular compound (Haug, 1993).

Verschueren (1983) determined the OI for many organic compounds, including those prevalent in composting operations. Compounds were divided into three categories: high odor potential ($OI > 10^6$); medium odor potential ($10^5 > OI > 10^6$); and low odor potential ($OI < 10^5$). Table 8.2 was derived from Haug (1993) and presents compounds likely to be encountered in compost exhaust gases; however, the nature of the feedstock (e.g., yard waste, biosolids, etc.) was not specified. Regardless, all compounds listed in Table 8.2 are characterized with high OIs.

Table 8.2

Odor Index for Selected Compounds

Compound	**Odor Index**
Ammonia	$1.67 \cdot 10^6$
Hydrogen Sulfide	$17.0 \cdot 10^6$
Methyl Mercaptan	$53.3 \cdot 10^6$
Ethylamine	$1.45 \cdot 10^6$
Ethyl Mercaptan	$289.5 \cdot 10^6$
Dimethyl Sulfide	$2.76 \cdot 10^6$

(Adapted from Haug, 1993)

Factors Influencing Odor Generation

Release of odors from a composting windrow is typically the result of anaerobic conditions within the system. Not only are these odors an unwanted nuisance, but they are generally a sign indicating that some essential management issue has been ignored. Subsequently, this section will discuss these issues in an attempt to minimize the conditions which can lead to odor formation.

Richard (1996b) specified four main factors responsible for causing anaerobic conditions, which lead to odor generation during composting: (1) excessive moisture; (2) inadequate porosity; (3) the organic constituents present; and (4) excessive pile size. Each of these factors is responsible for reducing pile aeration, which can lead to the generation of anaerobic zones within the compost pile. Therefore, it is imperative that sufficient aeration be maintained, as incoming yard waste contains high amounts of readily degradable material with a high demand for oxygen (*BioCycle*, 1989c).

The microbial community responsible for biodegradation receives its required oxygen via diffusion through the pore spaces of the windrow pile. Diffusion is a function of the concentration difference between the outside air, at 21 percent oxygen, and the oxygen concentration in the interior of the pile (Richard, 1996b). How effectively the microbial oxygen demand is met establishes whether the organic compounds degrade aerobically or anaerobically (Gage, 2003). Therefore, an oxygen concentration of 10 percent is recommended to ensure aerobic conditions are sustained. And, although composting literature readily agrees upon the recommended 10 percent, experimental evidence supporting this level was not ascertained during the course of this research.

Excess Moisture

Excess moisture has two ways in which it can lower oxygen diffusion in a compost pile. First, compost is characteristically hydrophilic, which causes any water in the pile to attach strongly to the surface of organic particles. As the moisture content of the pile increases, so does the thickness of the aqueous film around the particles. Secondly, capillarity causes a matrix effect that fills the smallest pore spaces with water first. This produces water-filled areas between particles, which creates anoxic clumps in the pile by slowing the integration of oxygen (Richard, 1996b).

As mentioned previously, Hamoda *et al.* (1998) indicated that values of moisture greater than 60 percent will significantly inhibit the organic matter degradation by microorganisms, because excess water will infiltrate the free air space between particles. Conversely, insufficient moisture will hamper the solubilization of nutrients in the organic matter that serve as the energy source for microorganisms.

Inadequate Porosity

Richard (1996b) stated that high levels of moisture in a compost mixture can interact with particle size distribution, bulk density, and porosity to affect oxygen transport. Smaller particle sizes increase microbial reactions, but they decrease the free air space available for oxygen diffusion. Consequently, particle sizes must be appropriately sized so that they generate sufficient microbial activity, while allowing for sufficient oxygen transport (Tchobanoglous *et al.*, 1993).

The size, shape, and structure of organic particles in a compost matrix affect how they will settle. Grass, for instance, has a very poor structure relative to other yard wastes, creating a tighter packing that increases the bulk density of the pile while

decreasing its free air space (Buckner, 2002). Therefore, great care should be taken to ensure bulking agents, such as wood chips, are incorporated into a yard waste composting operation in order to provide the oxygen essential for aerobic degradation.

Organics Present

Oxygen concentration within a compost pile is a function of the oxygen supply and the oxygen consumption. Rapidly degrading substrates such as grass clippings consume considerably more oxygen than leaves, thereby requiring a higher supply rate of oxygen to maintain a sufficient overall oxygen concentration (Richard, 1996b).

In a turned windrow operation, several methods can be employed to supply the increased oxygen required by a rapidly degrading substrate. First, as indicated above, limitations on oxygen diffusion such as inadequate porosity should be reduced through the use of bulking agents. Secondly, an intermediate-level approach to composting must be adopted, providing improved aeration through increased mixing (Strom and Finstein, 1989). A final alternative, which is commonly practiced with grass clippings, is to reduce the pile size (Richard, 1996b).

Excessive Pile Size

Constructing windrows too large at the onset of composting will not allow sufficient oxygen to penetrate the interior of the pile, developing a large anaerobic core. Tall piles can also increase compaction, which promotes tight packing and further reduces oxygen diffusion. Keeping piles relatively small for the first several weeks will allow for a more even distribution of oxygen, temperature, and moisture (Gage, 2003).

According to Richard (1996b), each composting systems has an ideal surface to volume ratio. Larger piles, with smaller surface to volume ratios will tend to overheat

due to lack of sufficient aeration. On the other hand, smaller piles may be too cool. Therefore, a standard windrow should be constructed where the width of the windrow is approximately double the height. The ideal height for an optimum surface to volume ratio will usually be in the range of three to ten feet (Richard 1996b). Grass, with its rapid degrading and high bulk density will be at the lower end of this range, while degrading, porous leaves should be constructed at the upper boundary (Richard, 1996b). It would be reasonable to assume then that a mixture of these two fractions would require a windrow height somewhere in between the two extremes.

Strategies for Odor Control

While the focus of odor control should always remain on prevention, some composters may feel that supplemental odor treatment is necessary, especially if the potential exists to offend residents adjacent to a compost facility. It must be emphasized, however, that the treatment methods introduced in this section are largely proprietary and, with the exception of a few proven methods (e.g., biofiltration), have the reputation of being illegitimate "snake oils." The purpose of this section, therefore, is to familiarize potential composters with their existence. At no time should these methods serve as an alternative to proper process management.

In general, three methods of active odor control are available to waste management facilities: air contact, surface contact, and incorporation (Bader, 2002b). According to Global Odor Control Technologies (2003), deciding which odor control method to employ depends on several factors, including the types of materials being composted, the composting method or technology being used, the site layout, and the

process activity generating the majority of odors (e.g., windrow mixing, screening, grinding, etc.).

Air Contact

With air contact, reactants and deodorizers are atomized into the same current of air carrying the malodorous gases (Bader, 2002b). If air contact is the chosen method, either a perimeter nozzle system is used or nozzles are attached directly to windrow turning machinery. This option may prove particularly effective if the majority of problems and complaints stem from compost turning operations. If odors are emitted as a result of screening or grinding operations, nozzles may be affixed directly to the equipment involved or to inlet and outlet conveyors attached to the equipment (Global Odor Control Technologies, 2003).

Surface Contact

Surface contact applications use topical sprays or mists that generate a reaction on the surface of the odor-causing material and subsequently treat compounds before they are released into the air (Bader, 2002b). Surface contact provides an appropriate solution if odor problems are infrequent or intermittent. Preferred by many site operators for its more direct approach, surface contact products can be applied directly to the compost pile from nozzles attached to the windrow turning machinery as it is being turned. And, surface applications can provide effective treatment if complex topography doesn't lend itself to perimeter air treatment (Global Odor Control Technologies, 2003).

Incorporation

Incorporation involves the addition of a substance into the waste substrate in an effort to alter the causal reactions that form the malodorous compounds (Bader, 2002b). Incorporation treatment is typically applied in aerated static pile operations. While the option of surface treatment is available after windrow formation, it is usually more efficient to incorporate a treatment product into the feedstock at the time of formation. The treatment product is blended into the incoming feedstock using a batch mixer (Global Odor Control Technologies, 2003).

Within the three broad categories of odor control are a variety of specific techniques for dealing with odorous compounds. These methods range from simply covering odors with more pungent, less offensive scents to breaking down the objectionable compounds with the employment of chemical oxidants. Discussed below are a few of the more popular approaches to odor control within the three aforementioned categories.

Masking Agents

Masking agents are the most common and least expensive method utilized for supplemental odor control. These perfumed scents, which work by covering odors rather than neutralizing them, come in various aromas to include citrus, cherry, and vanilla. Masking agents are often criticized because they increase the number of "odor units" around a waste management facility. A pleasant smell such as vanilla with an objectionable smell lingering underneath can still create a problem, because the masking agent has only served to raise the number of "odor units." Indeed, there can be too much of a good thing, as emphasized by specialty businesses such as bakeries that have

installed odor-control devices on some facilities to limit the annoyance caused by even agreeable scents after extended exposure (O'Connell, 1999). Subsequently, the ideal solution would call for the elimination or neutralization of the odor.

Neutralizing Agents

A neutralizing agent acts by countering an odorous compound with neutralizing chemicals, thus producing less overall odors. Neutralizing agents claim to thwart odorous compounds typical to composting operations, including amines, aldehydes, and mercaptans (Haug, 1993). Neutralizing agents are typically applied using equipment similar to that used for masking agents. Some manufacturers, however, market odor-neutralizing solid granules that can be placed in permeable sleeves around a facility's perimeter.

Chemical Oxidation

According to LaGrega *et al.* (2001), chemical oxidation serves to destroy a multitude of compounds including mercaptans and volatile organics through the addition of an oxidizing agent. Chemicals such as hydrogen peroxide, potassium permanganate, and chlorine are used to oxidize the compound of concern (LaGrega *et al.*, 2001). Care must be taken in this approach, as these compounds may kill the composting microorganisms as well, which is particularly true for chlorine. Oxidizing agents are typically incorporated when the incoming feedstock is being mixed, prior to windrow formation. If added at low concentrations and thoroughly incorporated into the feedstock, an oxidizing agent like potassium permanganate could prove very effective. However, this approach would be more expensive than masking (Richard, 1996c).

Catalysts

Richard (1996c) reports that catalysts claim to degrade odorous compounds with biologically generated enzymes. The catalyst can make a reaction proceed without being permanently changed itself. Consequently, a catalyst can act on many odorous compounds before it ultimately degrades. Enzymatic catalysts are normally applied using either surface or air contact. Many catalyst products are on the market, but limited independent research is available to verify their effectiveness.

Biofiltration

Biofiltration refers to the process of using a biologically active material to remove contaminants, including odorous compounds, from a given waste stream. Cured compost, in particular, has proven to be an effective media for biofiltration, demonstrating effective treatment of essentially all odors associated with composting, including ammonia and a wide range of volatile organic compounds (Richard, 1997). The compost product has a characteristically high absorptive capacity, meaning that odorous compounds can be physically sorbed onto the surface of compost particles as well as the surface of water surrounding the compost particles (Buchanan *et al.*, 1998).

A study by Yang and Allen (1994) demonstrates the ability of compost to effectively remove odorous compounds from the gas phase. In the study, compost was evaluated for its ability to remove hydrogen sulfide, a common odor in composting operations. When compost had a moisture content between 30 and 62 percent, the study showed that hydrogen sulfide removal efficiencies exceeded 99.9 percent. The reason for this astounding removal rate is the diffusion of the odorous compound into the water

phase, where subsequent microbial action takes place, forming simpler compounds and metabolic by-products.

The principles of biofiltration can be employed in lower-technology compost applications by placing a layer of cured compost on the surface of windrows. However, this is not practical for an open-air windrow operation that mechanically mixes compost piles on a weekly or bi-weekly basis. Available literature suggests that biofiltration techniques are best suited for compost processes that take place within buildings that have fixed exhaust points (e.g., in-vessel systems), or outdoor processes that utilize forced aeration techniques (e.g., static aerated piles) able to control the movement of air, thereby capturing and treating any malodorous compounds.

Weather Monitoring

BioCycle (1989c) recommends a final approach to minimize the offsite impact of odors if other steps to prevent their release are ineffective. This approach times windrow turnings to coincide specifically with favorable wind conditions, when the compost facility is downwind of residences and other sensitive land uses. In addition, higher wind speeds are preferable, as they correspond to more turbulent conditions which aid in the dispersion of any released odor. For this technique, a low-tech wind sock could be used to determine wind direction, but a device that determines both wind direction and speed would be preferable. An inexpensive computerized weather station will not only report what the weather is doing at any given moment, but it will also provide a historical record of wind patterns to fine tune future operations (O'Malley, 2003).

Finding a Professional Solution

Ultimately, if composting facility managers seek a supplemental approach to controlling odors, they can either work with a consultant to solve those problems, or work directly with a manufacturer. Either will assist a facility with appropriate application techniques and frequencies, but when choosing to work directly with a manufacturer, O'Connell (1999) recommends the following guidelines to ensure successful implementation of an effective odor control:

- Verify the technical competency of the manufacturer. Interview the manufacturer to ensure they have the experience necessary to suit the needs of a given facility.
- Ask the manufacturer for specific examples of successful applications used to control odors at similar compost facilities.
- Insist that the manufacturer provide specific chemical reaction data for their products. This not only helps to educate the user on the particular neutralization technique employed, but it will further establish the manufacturer's expertise.
- Look for a manufacturer that provides delivery systems in addition to neutralization agents. One company's delivery system may not be optimal for another company's odor-controlling material.

Communicating with Nearby Residents

Effective odor control must include proactive communication with nearby residents to ensure success. Recurring informational meetings will educate residents and help them to realize that even the best-managed compost facilities will occasionally emit

odors. Frequent tours and open houses will also assist in avoiding problems. The use of an early warning system should also be considered if weather conditions or compost characteristics make it likely that nearby residents will detect foul odors. Ultimately, residents must be assured that any odors they notice, while perhaps unpleasant, are not a threat to their health (Feinbaum, 2000).

CHAPTER 9

GRASS CLIPPINGS: INCORPORATE WITH CARE

While the threat of odors exists when any yard waste is composted, introducing grass clippings into the mix can intensify the problem. And, as more grass clippings are added to the feedstock, the probability of odor problems increases, making them a menacing addition to a municipal yard waste composting operation. In fact, South Carolina DHEC (2002c) states that grass clippings constitute as much as 70 percent of yard waste collected during an active growing season. This sizeable amount of grass contains high nitrogen levels which can lead to the release of ammonia during aerobic composting and amine compounds during anaerobic conditions (Glenn, 1990). Grass also has a very poor structure relative to other yard wastes, giving it a greater tendency to mat. This characteristic reduces the pore volume of the windrow, which can lower the available oxygen content of the pile, subsequently improving the odds that anaerobic conditions with increased odor will be created (Buckner, 2002).

If grass clippings are to be incorporated into a municipal yard waste composting operation, extra attention must be taken to prevent windrows from becoming anaerobic. Like most yard waste composting facilities in operation around the country, the Anderson County facility being considered for development would likely employ an outdoor turned windrow system. Because this type of facility offers limited opportunity to contain and treat any odorous off gassing, the primary means to ensure effective incorporation of grass clippings into a feedstock with subsequent minimization of odor generation is by sensible process management (Buckner, 2002).

Process Management

Buckner (2002) conducted a comprehensive research project at the Islip, New York composting facility to determine windrow management practices that most effectively control odors when dealing with grass clippings. Experiments were conducted using windrows constructed of grass clippings and varying ratios of wood chips or partially decomposed leaves collected the previous fall. The experiments evaluated the effects of the assorted ingredients on odor concentrations, keeping the moisture content of each windrow at optimal levels while turning each pile twice per week.

The results of the experiment demonstrated that the windrows composed of grass and woodchips showed the most considerable reduction in odor concentrations. The odor concentrations in the 2:1 (by volume) wood chip to grass mixture decreased most dramatically and remained low throughout the remainder of the experiment, while the odor concentrations in the 1:1 wood chip to grass mixture decreased less significantly, but were otherwise similar to the 2:1 mixture. In contrast, the odor concentrations in the mixtures consisting of leaves and grass tended to decrease more slowly, clearly indicating that feedstock mix is essential to managing odors (Buckner, 2002).

While wood chips may serve to provide increased reduction in odor concentrations (doing so primarily by providing better aeration), they do not provide adequate levels of available carbon to balance the high nitrogen levels inherent in grass clippings. Although wood chips have a high carbon to nitrogen ratio, the carbon in the wood is relatively unavailable to the microbial community. Furthermore, unless wood

chips are a desirable constituent in the final product, separation by screening will be required (Strom and Finstein, 1994).

If grass clippings are to be incorporated into a yard waste composting operation, Strom and Finstein (1994) recommend a ratio of no less than 3 volumes of partially decomposed leaves to 1 volume of grass clippings to form windrows with dimensions no greater than 6 feet high by 12 feet wide. Good mixing of these ingredients is essential and should preferably be accomplished with a specialized windrow turning machine to ensure thorough mixing. However, since partially decomposed leaves collected the previous fall have usually lost half of their original volume by the time grass clipping collection begins in the spring, the recommended amount of grass clippings to be handled is actually one sixth the volume of leaves originally collected. More importantly, the volume of grass clippings collected is nearly equivalent to the volume of leaves collected, underscoring the need to minimize the collection and subsequent incorporation of grass clippings into yard waste composting operations (Strom and Finstein, 1994).

Grass Recycling

Grass clippings are readily biodegradable, but the care that must be taken to incorporate them with other sources of yard waste begs the question: why collect grass clippings at all? Accordingly, municipalities should devise and implement public awareness campaigns aimed at encouraging residents and lawn care services to leave grass clippings on the lawn, thereby minimizing the amount of grass clippings that require composting. This practice of grass recycling is very advantageous, as it reduces water evaporation from the lawn, creates a cushioning layer that reduces lawn wear, and

facilitates better growth by keeping soil temperatures cooler and providing nutrients and organic matter essential for healthy lawns (SC DHEC, 2002c).

During the heavy summer growing season, grass should preferably be mowed at approximately 5-day intervals. This frequency will serve to remove only the top third of the grass blade, allowing the clippings to penetrate the remaining grass and biodegrade at the soil surface, providing vital nutrients such as nitrogen and organic matter. While any mower can be used for this purpose, mulching mowers or mowers with mulching attachments on traditional rotary machines will make the grass clippings biodegrade more efficiently by processing the grass more finely than conventional mowers (Forsell, 1995). If the mulching mower is functioning properly, freshly mowed lawns will have a vacuumed appearance with no unattractive clumps or hedgerows of grass.

In addition to frequent lawn mowing as discussed above, South Carolina DHEC (2002c) offers the following suggestions to ensure a healthier and greener lawn:

- Keep mower blades sharp. A sharp blade will not only provide a cleaner cut to the grass, but it will also disperse the cut grass better than a dull blade.
- Mow when the lawn is dry. An even cut can be difficult to achieve with wet grass. Additionally, wet grass can dull mower blades and reduces dispersion of the grass clippings by forming clumps.
- Avoid over-fertilizing. Using fertilizers excessively can produce a lawn with too dense growth, making it difficult for the clippings to reach the soil surface and subsequently decompose.

Allowing grass clippings to remain on lawns saves several valuable resources. First, it saves time, eliminating the need to repeatedly empty and reattach the collection

bag. Grass recycling also saves money for residents by adding nutrients to the lawn from the clippings, thereby reducing the need for supplemental chemical fertilizer. This, in turn, reduces the potential for nitrogen surface water contamination resulting from the application of the chemical fertilizer (SC DHEC, 2002c). Furthermore, municipalities save money by reducing collection costs. And, most importantly, leaving grass clippings in place alleviates the need for landfill disposal, freeing space for other municipal solid waste sources.

CHAPTER 10

RISKS ASSOCIATED WITH COMPOSTING

In general, composting today is looked upon favorably by the public. But, while citizens may view composting as a clever method to recycle their solid waste, they are undoubtedly concerned about the public health and environmental issues related to such operations. Whether it is problems facing facility operators during the processing of compost or constituents present in the end product that inhibit plant growth, these concerns must be taken seriously. Accordingly, the following section highlights some of the more common risks associated with the processing and use of compost.

Fire Hazard

Normally, fire is not a problem many compost facilities must contend with. Minimum ignition temperatures for organic materials vary based on numerous environmental conditions, but normally range between 121° C and 204° C (250° F and 400° F). Given that composting temperatures typically peak at 70° C (158° F), the risk of windrow ignition is highly unlikely. And, windrows with proper moisture levels above 40 percent severely diminish the likelihood of such an event (*BioCycle,* 1999e).

Combustion is also not likely to occur if organic material is too dry, given that microbial activity is severely inhibited. But, dry conditions can be a concern if facility security is inadequate, allowing vandals to ignite the dry surface of windrows. Additionally, if the moisture content of organic materials ranges between 25 and 40 percent, the possibility of combustion increases (*BioCycle,* 1999e). For these reasons,

creating and implementing a fire plan is an essential part to any well-managed compost facility.

A sound fire prevention plan can be attained by first installing a perimeter fence around the facility to reduce the chance of windrow ignition by vandals. A fire program can be further accommodated by having a ready water supply and means for delivery, and by providing sufficient aisle space between windrows for increased access and to act as a fire break (Strom and Finstein, 1994).

Aspergillus fumigatus

Appropriate consideration to worker health and safety concerns can reduce occupational risks at municipal compost facilities. One concern, in particular, to composting facilities is the ubiquitous fungus, *Aspergillus fumigatus*. It is found all over the world and is common in soils, compost, hay, grain, and decaying vegetation. It is tolerant of thermophilic temperatures, and can therefore withstand the composting process (Epstein and Epstein, 1989). Spores from this organism can cause allergic problems for hypersensitive compost workers, especially if the compost is dry and dust is inhaled from grinding, screening, and windrow turning operations (Dickson and Richard, 1989).

Studies conducted by Clarke *et al.* (1984) found no consistent difference between the incidence of allergic response by *Aspergillus fumigatus* between compost workers and workers not involved in compost operations. The studies showed that although colonization of the fungus is more common in compost workers due to its increased occurrence, subsequent allergic problems are no more frequent. Regardless, simple safety precautions can and should be taken to protect worker safety. The risk of infection

can be significantly reduced by ensuring that windrows maintain sufficient moisture levels and by requiring the use of dust masks should dry and dusty conditions occur (Dickson and Richard, 1989).

Pathogens

The main pathogenic microorganisms encountered in composting can be bacterial (e.g., *Salmonella*), viral (e.g., hepatitis), helminths (e.g., roundworms and tapeworms), and protozoa (e.g., *Giardia lamblia*). In yard waste composting, the potential pathogens encountered result mainly from the occurrence of pet feces. If not properly treated, these pathogens can serve as infectious agents and cause numerous diseases (Epstein and Epstein, 1989). However, a properly managed composting process should alleviate any concerns for pathogenic endurance. As set forth in Title 40, Part 257, Appendix II of the *U.S. Code of Federal Regulations* (1996), turned windrows should attain a temperature of 55° C (131° F) or greater for at least 15 days during the composting period, with a minimum of five turnings during that 15-day period. Although created to address the composting of biosolids, these criteria have been adopted by composters of other feedstocks, to include yard waste. Followed closely, these procedures should ensure the complete destruction of all pathogens throughout the windrow (Kashmanian, 1993).

Soluble Salts

According to *BioCycle* (1999f), soluble salts are inorganic or mineral compounds that readily dissolve and separate into ions in solution, representing easily available plant nutrients. And, while salts formed by nitrogen, potassium, calcium, and sodium are abundant in compost, their presence is not necessarily harmful. But, as is often the case, there can be too much of a good thing.

An exceeding high salinity level can adversely affect plant growth, causing damage to both crops and seedlings. If compost is the sole potting media intended for plants, the electrical conductivity should not exceed 2 millimhos per centimeter (Kashmanian, 1993). In most applications, however, compost is typically mixed with soil, allowing for higher electrical conductivity levels in the finished compost (*BioCycle*, 1999f). Therefore, an acceptable salt concentration in compost is a subjective measure, depending on application practices. *BioCycle* (1999f) recommends 10 millimhos per centimeter as a rough guide for soluble salt concentration in finished compost. Any concentration exceeding this amount might cause concern for discerning consumers. As a consequence, the concentration of soluble salts in compost should be closely monitored.

Not surprisingly, the primary source of soluble salts in the finished compost is the initial feedstock. One method to reduce the salt concentration in compost is to select a feedstock with lower salt levels. For example, manure and food scraps tend to have higher salt concentrations, while leaves and other yard wastes typically contain lower salt concentrations (*BioCycle*, 1999f). This assertion is supported by tests in Portland, Oregon, where yard trimmings compost was found to have safe soluble salt concentrations ranging from 0.17 to 1.9 millimhos per centimeter (*Portland Metropolitan Service District,* 1989). Additional tests at Cornell University on composted yard waste found soluble salt concentrations well below unsafe levels (Richard and Chadsey, 1989).

Pesticides and Herbicides

Every year in this country, over 30,000 tons of pesticides and herbicides are applied to lawns, turf farms, and gardens (Michel *et al.*, 1996). One of the most widely used of these pesticides is diazinon, with an estimated 5,000 tons used per year (Michel *et*

al., 1996). Likewise, a commonly applied herbicide, known as 2,4-D, has an estimated use of 3,000 tons per year (Michel *et al.*, 1996). With such large quantities of these chemicals introduced to the environment each year, it's only natural that questions would arise regarding their fate during composting. Even at parts per billion levels, diazinon can be toxic to fish and birds, and as little as 2 parts per million of 2,4-D in soil can significantly reduce plant growth (National Research Council Canada, 1978). Accordingly, compost users and producers alike want to know if pesticides and herbicides will be present in the finished product and, if so, what environmental impacts are likely. Concerns also include the human health effects from eating crops grown from compost amended soil, or from children ingesting the compost directly (Strom, 2000).

Significant Declines in Pesticide Concentrations

Limited published literature exists on the fate of pesticides in yard waste composting, but what does exist supports the notion that low concentrations of pesticides are to be expected in collected yard waste and extensive declines in these concentrations will take place during the composting process (Strom, 2000). For example, Michel *et al.* (1996) conducted a 50-day laboratory study simulating the temperature and aeration conditions common in windrow composting and found sharp reductions of diazinon, 2,4-D, and pendimethalin. And, although the 2,4-D was reported to be substantially mineralized, the extent of this mineralization was not quantified.

In another study, several samples of grass clippings at a Massachusetts composting site were analyzed before composting and found to contain low concentrations of 2,4-D, dursban, and pendimethalin. However, the finished product contained no trace of pesticide residues (Fulford *et al.*, 1992). Similarly, in another study

conducted by Lemmon and Pylypiw (1992), grass clippings were dosed with diazinon, chlorpyrifos, isofenphos, and pendimethalin. The samples then underwent 17 weeks of simulated composting, after which time pesticide concentrations were not detected.

An additional study by Strom (2000) analyzed compost samples from six New Jersey facilities for 27 commonly used pesticides and polychlorinated biphenyls (PCBs). The analysis found no detectable levels for 26 of the pesticides or the PCBs in all samples. Chlordane, however, was detectable in each sample, ranging from 0.29 to 3.23 parts per million. According to Richard and Chadsey (1990), chlordane has not been used in the United States since 1988, but from 1983-1988 chlordane experienced widespread use for termite control, and prior to 1983 it was also used in lawn, garden, and agricultural applications. Given chlordane's strong adsorption capacity to the organic fraction of soil, any amount of the compound in finished compost is probably the result of residues in the soil inadvertently picked up with leaves during raking. Thus, since soil is the source of chlordane, residential use of compost derived from yard waste would pose no greater risk of pesticide contamination than does the soil itself. Additionally, any chlordane in the compost or soil is not expected to be taken up by plant roots, nor transferred to plant leaves (Strom, 2000).

In addition to the above findings, Strom (2000) presents several factors that further support the fact that applications using finished compost are safe: 1) in general, lawn care providers now use reasonably low concentrations of non-persistent pesticides (e.g., organophosphates); 2) while homeowners may use higher concentrations of improperly applied pesticides, these levels will be diluted by the majority of lawns that are not treated, or are treated correctly by professionals; 3) shade trees, which constitute

the major source of leaves for composting, receive comparatively low concentrations of non-persistent pesticides; and 4) because the majority of pesticides in use today are non-persistent, the low concentrations initially present in virgin feedstock are expected to reduce significantly during the composting process. However, as will be discussed later in this chapter, laboratory testing is the only reliable technique to determine the actual concentration of pesticides and herbicides in compost.

Adverse Effects in Washington State

Overall, microenvironments within a given composting environment experience significant fluctuations. As indicated in the above findings, these variations have a positive effect on most pesticides, degrading them as they are exposed to diverse microbial populations and successive shifts in temperature, pH, and oxygen levels (Büyüksönmez *et al.*, 2000). Nevertheless, while these findings are reassuring, compost products from two facilities in Washington State were reported to be contaminated with different herbicides, causing damage to vegetation and gardens (Rynk, 2000b).

Compost produced at the Spokane, Washington facility was found to be contaminated with trace levels of the herbicide clopyralid, causing damage to tomato seedlings at a commercial greenhouse. The Spokane composting facility used a turned windrow composting system to handle 25,000 tons of yard trimmings annually, including grass and branches. Most likely, the source of the herbicide was from the grass clippings of lawns treated with clopyralid to combat dandelions and clover (Rynk, 2000b).

The Pullman, Washington facility produced compost that caused damage to plants being grown in a community garden. The Pullman facility also used a turned windrow technique to compost approximately 25,000 cubic yards of feedstock that includes

manure, food scraps, animal bedding, and plant material from landscaping and greenhouses. A series of laboratory analyses, coupled with tracking of possible feedstock contaminants identified picloram as the contaminant. Picloram is an ingredient in herbicide products used to combat thistle and broadleaf weeds. It appears that picloram was used to treat pastures later converted to hay. The hay was then ingested by livestock and the picloram subsequently passed through the animals, primarily via urine, and accumulated on both the manure and bedding (Rynk, 2000b).

Clopyralid and picloram are both moderately to highly persistent in soil and are therefore slow to degrade. In fact, herbicide products containing these two compounds have associated labels cautioning users that compost containing treated grass clippings or crop residues should not be used in the growing season that the herbicide was used. It's not that the chemicals did not degrade in the composting process at both Washington sites, but rather, they did not degrade sufficiently to provide a compost product that would be entirely harmless to plants (Rynk, 2000b).

Although the composting process can speed degradation, high levels of organic matter can bind pesticides and herbicides, thereby retarding their rate of decay. Evidence of this occurrence has been linked with picloram, and possibly clopyralid by association. And, to compound the problem, rapidly degrading feedstocks such as grass clippings can further increase the concentration of even a highly degradable chemical, because the feedstock decomposes substantially faster (Rynk, 2000b).

If the use of these persistent pesticides or herbicides are detected or suspected in incoming feedstock, the use of the finished compost becomes an essential factor. For example, if compost contaminated with low concentrations of persistent herbicides was

used for turf or grass applications, no problems would be anticipated. If, however, the contaminated compost was to be used in a garden growing sensitive plants such as tomatoes, negative effects would be likely (Rynk, 2000b).

In a response to the incidents at the two Washington compost facilities, the Washington Organics Recycling Council cited overapplication of compost as a main factor (Rynk, 2000b).. In Spokane, compost was used as the sole potting media for the affected tomatoes, while in Pullman, compost was applied to the community gardens at much higher rates than the one-half inch layer recommended by the Pullman composting facility. Even with the use of contaminated compost, these incidents could very well have been avoided if properly mixed with soil or other planting media (Rynk, 2000b).

Even though these incidents have highlighted the potential problems associated with the application of contaminated compost, they are indeed isolated. In fact, Rynk (2000b), in association with *BioCycle* magazine, has not identified any additional confirmed cases of inhibited plant growth resulting from the use of compost containing herbicide residues. This suggests that end users of compost should maintain confidence in compost as a safe and beneficial soil amendment.

Yet, any responsible municipality preparing to implement its own yard waste composting facility should exercise sound judgment and plan to analyze mature compost, at least initially, to ensure it contains no pesticide or herbicide concentrations capable of causing deleterious effects on either human health or the environment.

Recommended Testing Methods

The U.S. Composting Council, a non-profit national organization committed to the advancement of the composting industry, created a standardized evaluation program

known as Test Methods for the Examination of Composting and Compost (TMECC). According to the U.S. Composting Council (2003a), TMECC provides the necessary protocols for laboratories to verify the physical, chemical, and biological condition of composting feedstocks, material in process, and cured compost products at the point of sale. This program not only aids in maintaining process control, but it also assures the safety of facility workers and helps to avoid adverse effects to the environment in and around the compost facility. Table 10.1 provides a brief description of various tests performed by participating TMECC laboratories. This table is not intended to be all inclusive. Rather, it is intended to demonstrate the wide array of tests that can be performed by a TMECC laboratory.

Table 10.1

TMECC Laboratory Analysis

Parameter	**Analysis**
Physical	Air capacity, bulk density, wettability
Chemical	Nutrient content, heavy metal content, electrical conductivity
Organic and Biological	Color, odor, organic matter, viable weed content, respirometry
Synthetic Organics	Chlorinated herbicides, organochlorine and organophosphorous pesticides
Pathogens	Coliform bacteria, *Salmonella*, parasitic helminthes, culturable viruses

It is the goal of the U.S. Composting Council to bring consistency and credibility to the compost industry by having all compost producers participate in a program to regularly sample their product using approved TMECC laboratories. Testing frequency is based upon the volume of compost produced by an individual facility, and can range from monthly for larger compost producers (greater that 17,500 tons of compost per year) to quarterly for smaller producers (less than 6,250 tons of compost per year). Based upon current yard waste estimates, Alexander (2003) states that Anderson County would be required to have their compost tested once every other month, and can expect to pay $2,000 per year to participate in the TMECC program. In general, the collection protocol for a single test requires the compost facility to cut into the finished compost pile at five randomly selected positions. Then, five point samples are collected at three separate depths in each cutout, for a total of 15 samples per cut, or 75 samples per windrow. All 15 point samples from one cutout are placed together into one sanitized, 5-gallon plastic pail and completely mixed. Each of the five pails is then covered, sealed, and delivered to an approved laboratory for testing (U.S. Composting Council, 2003a).

Upon receipt of the laboratory test data and other applicable fees and information, the U.S. Composting Council will certify the participants' compost and permit the use of the "Seal of Testing Assurance" logo on all literature and bagged product (U.S. Composting Council, 2003b). Of course, provisions should be made in the event the compost does not pass the test and cannot be certified (e.g., landfill disposal, landfill cover, etc.).

CHAPTER 11

MARKETING

As noted previously, implementing a composting operation has many attractive benefits, such as the conservation of landfill space and the production of a useful end product. Nevertheless, diverting yard debris from the landfill is only temporary unless markets for compost can be identified and stimulated. Otherwise, unwanted oversupplies of compost will inevitably result. Consequently, this discussion will focus on the four main requirements for the successful market development of compost. According to Kashmanian (1993), those factors are: (1) producing compost with consistent quantity and quality; (2) identifying viable uses for the compost; (3) identifying potential consumers (or markets); and (4) educating potential consumers with the product and its uses. Additionally, barriers to marketing compost will be explored.

Compost Quality

Without a consistent, reliable product to market, compost manufacturers will undoubtedly fail to establish a favorable reputation among consumers. This fact makes consistent quality one of the most important factors affecting compost marketability. Regardless of the technology utilized to generate the end product (e.g, static aerated piles, turned windrows, etc.), compost quality is a function of the product's physical, chemical, and biological characteristics (Kashmanian, 1993).

Biologically speaking, the end product should be mature with low microbial activity and have no detectable pathogenic organisms or active weed seeds. Beneficial

chemical characteristics include the availability of nutrients such as nitrogen and phosphorous, low salinity levels, and non-damaging levels of pesticides, herbicides, and heavy metals. And as for positive physical attributes, consumers prefer compost with a dark color and uniform particle size, no unwanted substances such as plastic or metal, and a rich earthy smell (Kashmanian, 1993).

Compost Uses

The value of compost as a soil amendment has long been recognized. Compost, with its high organic matter content, can improve a soil's texture and nutrient content, increase water retention, and enhance aeration capacity. In addition, compost can also be used for other applications such as a top dressing to reduce evaporation and inhibit weed growth and as a disease-suppressing treatment for wounded trees. Refer to Chapter 2 for a more in-depth discussion on the many benefits and uses of compost.

Not surprisingly, composts derived from different feedstocks have different characteristics. The uses for these compost products can, therefore, differ. According to Kashmanian (1993), yard trimmings compost typically has a more consistent composition than that of compost derived from mixed MSW, giving it a more consistent quality with higher consumer acceptance.

Compost Markets

Compost, with its many benefits, can be used for a multitude of applications. These applications can be grouped into agricultural, landscape, nursery, public agency, and residential categories. These groups are represented by various local and national organizations to include farm bureaus, landscape contractor associations, public works representatives, garden clubs, etc. These organizations represent strategic contacts able

to stimulate compost use by their members. However, uses of compost in each market can differ based on individual requirements (Kashmanian, 1993).

Agricultural

While the agricultural industry represents the largest potential market for compost use, they are the hardest to infiltrate given the longstanding use of fertilizers. Not only would farmers need to be persuaded through lengthy field tests, but the huge quantities of compost required for application can only be supplied by the largest of facilities. There is, however, the opportunity to focus compost sales on organic farming within the agricultural industry. Using no fertilizers or pesticides, organic farmers could benefit from the nutrients and pathogen protection provided by compost (Kashmanian, 1993).

Landscape Industry

The landscape industry has a high potential for using compost, but that use is largely dependent upon trends in the housing market, as home sales have a direct effect on the demand for landscaping services. Landscaping professionals typically uses large amounts of organic amendments, with bark being the highest seller due to its appeal as a top dressing. And, while compost is not expected to compete directly with bark sales, several studies have shown that landscapers are fully aware of the benefits of compost derived from yard waste (Cal Recovery Systems, Inc., 1988). Regardless of benefits, landscapers have expressed concern that yard waste compost may contain viable weed seeds and residues from herbicides and pesticides (Kashmanian, 1993). But, as discussed in the previous section dealing with risk factors, proper compost management coupled with an appropriate testing and certification program will alleviate these common concerns.

Nursery Industry

The nursery industry is similar to the landscape industry in that sales are greatly dependent on the economy and housing market. But, the nursery industry offers significant potential as a market for compost. As discussed earlier, compost provides vital nutrients and aids in water retention. Subsequently, compost could be marketed to the nursery industry as a more favorable alternative to peat, which tends to be more expensive and is often imported (Kashmanian, 1993). In order to supplant the use of peat in nursery applications, however, testing and certification of the compost should be accomplished to provide end users with the assurance that they are receiving a safe and reliable product.

Public Agencies

According to Kashmanian (1993), the diverse responsibilities of public agencies allow them to use composts of varying quality. Higher-quality compost can be used in parks and other recreational areas as a turf builder and maintainer. On the other hand, lower-quality compost can be used as either fill material or landfill cover.

A study conducted by the City of San Jose, California (1988) identified additional ways compost could be utilized by public agencies. One use is to apply compost for land upgrades, which enriches the soil and provides increased water retention, thereby requiring less water for irrigation. The land can then be used to support community activities such as gardening. Another use for compost is in roadway maintenance to control the growth of weeds or to improve soil conditions for median strip landscaping.

With the assistance of legislative initiatives, the use of compost products by public agencies can be virtually guaranteed. State and local governments can pass

legislation mandating that all public agencies responsible for the maintenance of public lands shall, to the maximum extent possible, use compost materials in all land maintenance activities paid for using public funds (*BioCycle* Staff, 1989d). In addition to use by public agencies, legislation could also specify use of compost by all private contractors performing maintenance on publicly owned lands.

Residential Users

Coupled with a strong and informative marketing campaign, the residents in a community can represent the most substantial market for municipally produced compost. According to a Portland, Oregon marketing study, residents indicated that they would be more willing to use compost produced solely from yard trimmings than from mixed MSW, but the extent of their purchasing would rely heavily on public education and the ability of the compost facility to produce an end product of consistently high quality (Portland Metropolitan Service District, 1989). Additionally, areas with high-density, apartment-type housing would show less demand for compost than single-family communities (Kashmanian, 1993).

Consumer Education

Even if a municipal facility is adept at producing consistently high-quality compost, the level of public awareness regarding the benefits and uses of compost will ultimately affect how much compost will be used. Accordingly, a municipal facility wishing to generate a demand equal to its supply must consider the use of various measures of advertising and publicity.

A well-rounded public awareness campaign should be both informational and educational. To illustrate this point, a yard waste composting facility in Ramsey County,

Minnesota used television and radio spots for informational purposes. The "what, where, and when" were addressed in these short 20- to 30-second public service announcements, while the "why" was the focus of the educational portion of the campaign. Newspaper articles, brochures, and media events provided the proper vehicles to ensure the benefits of compost use were fully conveyed (Golob, 1989).

Market Barriers

In order to implement a successful compost program, it is necessary to distinguish and understand the potential economic and non-economic barriers to developing a market for compost, as identified by Kashmanian (1993). And, while barriers may exist, they can most definitely be overcome.

It is important to note that numerous legal constraints and restrictive-use policies for compost exist as market barriers, but these pertain mainly to the highly-regulated biosolids composting industry. Given that these stringent restrictions are not germane to the needs of Anderson County, this section will briefly discuss some of the more important barriers applicable with yard waste composting and offer strategies for their mitigation.

Failure to Identify Potential Markets

Identifying compost markets should ideally take place before production begins, as it will serve to determine quality requirements for the end product. Additionally, if multiple markets are identified, projected amounts of various compost grades can be estimated. Failure to properly identify all available markets can lead to an overproduction or underproduction of certain grades of compost, resulting in unwanted stockpiling or failure to meet product demand (Kashmanian, 1993).

A market survey will be required to ensure all potential users within a given area are identified. A thorough survey should not only determine interested parties, but also recognize their specific needs as to quantity and quality of compost.

Cost Pressures from Competing Markets

In order to compete with similar products, compost must be competitively priced. Competing products will likely be of consistently high quality and have a reputation for being readily available. If compost is not of equal or exceeding quality and has varying availability, then its ability to compete successfully will be extensively diminished (Kashmanian, 1993).

BioCycle (1985) indicated that some communities initially offer compost for free or at reduced prices in order to infiltrate the market. Another method to combat cost pressures from competing markets would be to establish a pricing structure based on purchase quantity and distribution method. For instance, greater quantities of compost could be purchased at reduced rates, while those who pick up the compost at the production facility would be charged considerably less than those who have compost delivered (Cox, 1989).

Post-Processing Costs

Shredding, screening, and bagging are all common post-processing activities intended to increase the value of compost. However, these additional steps in the production process can serve as potential economic barriers if they are not accomplished cost effectively. Additionally, it may be unnecessary to engage in thorough post processing if the intended end use of the compost is for a low-quality, restricted use such as daily landfill cover (Kashmanian, 1993).

The solution to avoiding economic barriers in post processing goes back to identifying potential users and their needs as to the specific characteristics of the compost. Furthermore, factors such as inspection of incoming material, preliminary facility separation, and technology utilized at the facility can limit the extent of post processing. If, however, post processing must be accomplished to attain a high grade of compost, increased production costs can be recovered through increased revenue, provided that the higher-grade compost is sold at a competitive price (Kashmanian, 1993).

Transportation Costs

Transporting compost from the production facility to the end user can significantly influence the success of marketing compost. However, transporting compost over long distances is not typically feasible, because compost is a low-value product with a low bulk density. As a consequence, the cost of transportation will inhibit the development of compost markets far from the production facility (Kashmanian, 1993).

In terms of transportation, the least expensive option is to offer bulk pick-up service at the production facility and avoid transportation costs altogether. If, however, the compost facility wishes to reach a larger market through transporting its product, utilizing vehicles that deliver incoming feedstock can significantly lower costs. Rather than allowing these vehicles to return empty to their point of origin, finished compost can be delivered back to their communities in the same vehicles, provided they are satisfactorily cleaned to avoid the reintroduction of weed seeds and pathogens (Kashmanian, 1993).

Compost Quality Assurance

Two important tasks in the development and maintenance of a viable compost market are the establishment of an acceptable set of standards for the end product, and to ensure that end product consistently meets those standards. The task of ensuring a consistent product is particularly essential, in that it is necessary in building a positive reputation. Additionally, any deviations from established standards can lead to consumer frustrations and, when dealing with commercial consumers (e.g., farmers, landscape specialists, etc.), to loss of revenue (Kashmanian, 1993).

Kashmanian (1993) recommends actively seeking the involvement of potential consumers. By identifying their specific needs and focusing on which compost characteristics they feel are essential, compost manufacturers can create effective quality assurance measures. And, as mentioned previously, involvement in a certified laboratory screening program will ensure standards and specifications are met.

Implementing quality assurance measures will undoubtedly aid in establishing and maintaining a favorable reputation, but it may lessen the volume of marketable product. While unfavorable for the compost producer, this issue can be resolved by developing markets for several different grades of compost. Top-quality grades, for instance, could be sold for unlimited use, while lower grades could be utilized for restricted applications (Kashmanian, 1993).

CHAPTER 12

DESIGN AND COST DATA FOR ANDERSON COUNTY

This chapter begins by introducing the proposed location for Anderson County's municipal yard waste composting facility, making reference to the site selection criteria discussed in the Chapter 7. Next, in an effort to provide county officials with a comparison of land requirements and processing times associated with various composting methods, both low-level and intermediate-level technology designs will be presented and discussed. Finally, equipment needs as well as capital and operating costs for the two different approaches will be explored.

Proposed Site Characteristics

Figures 12.1 and 12.2 show the location of the proposed site for Anderson County's municipal yard waste compost facility. The property is located approximately two and a half miles north of Starr, South Carolina, along state Highway 81. The land is adjacent to the Starr C&D Landfill and encompasses a total area of 92.5 acres. Although this property was purchased primarily to accommodate an anticipated 50-acre expansion for Anderson County's C&D landfill operation, sufficient land is available on the site to also accommodate a composting facility. Consequently, this section will examine the characteristics of this site, paying particular attention to South Carolina regulations in an effort to determine if the property duly meets general siting criteria for a yard waste composting facility.

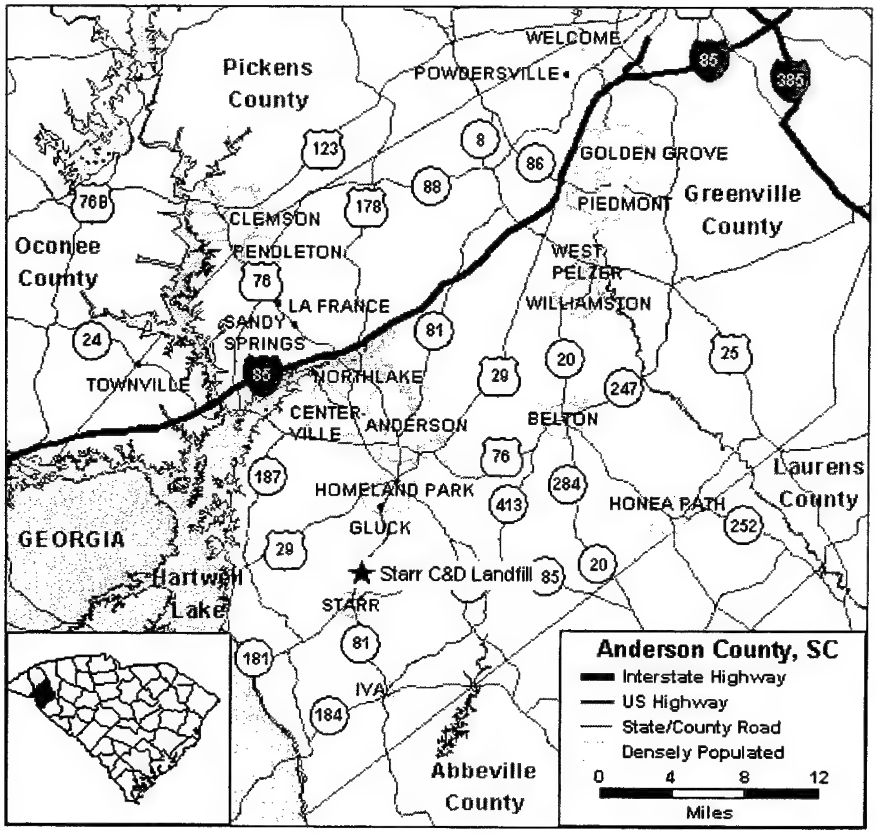


Figure 12.1 Map of Anderson County

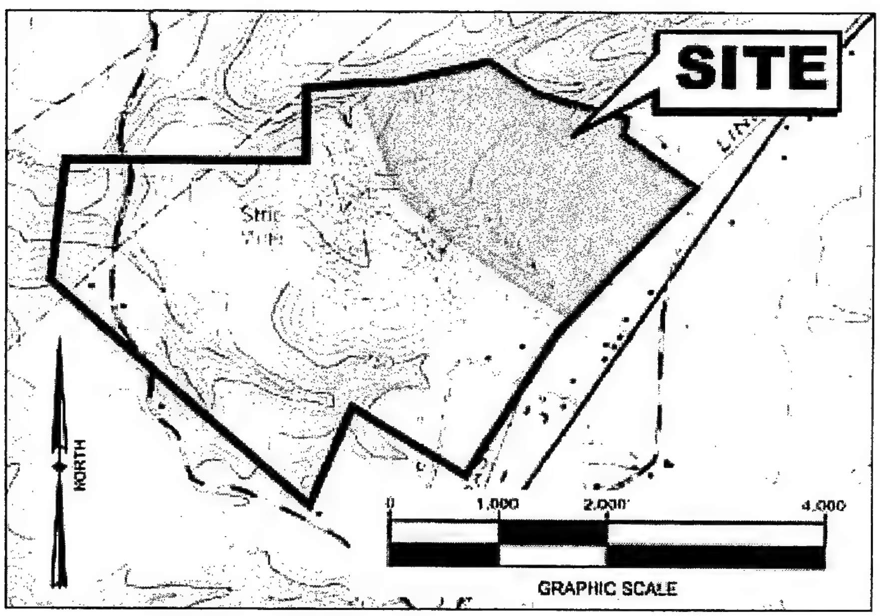


Figure 12.2 Proposed Site for the Anderson County Compost Facility

Site Location

As previously mentioned, a compost facility should be located in a centralized area adjacent to activities such as golf courses, and landfills. Using these criteria, the proposed site would seem ideal, as it is located adjacent to the Starr C&D Landfill which is situated in close proximity to a community golf course. Moreover, as Figure 12.3 illustrates, the area surrounding the landfill is sparsely populated. According to 2000 Census data for Anderson County, only 81 housing units with approximately 201 residents are located within a half-mile of the landfill's borders (Newton, 2003). And, because the proposed site is adjacent to the current C&D disposal site, it will not generate increased transportation time or costs, making the area economically appealing as well.

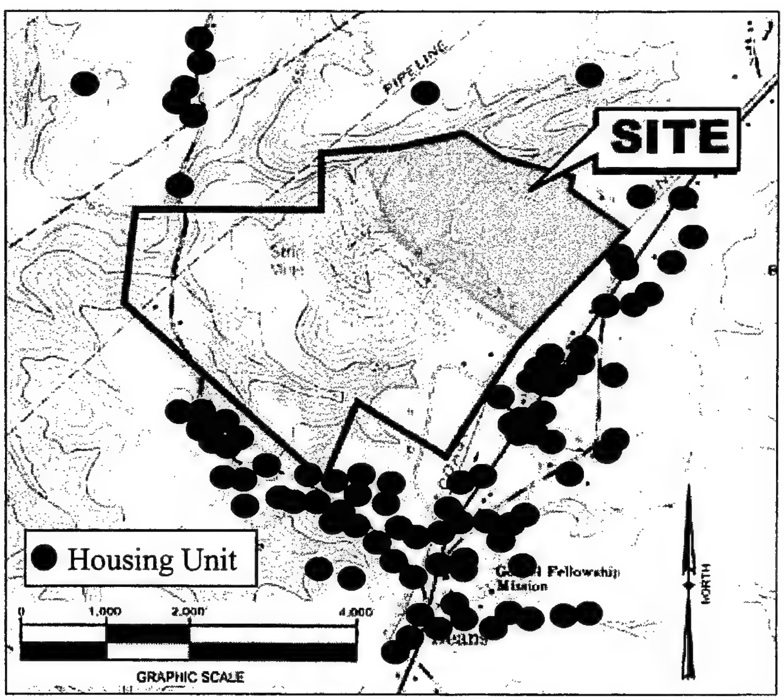


Figure 12.3 Population Density Adjacent to the Starr C&D Landfill

Water Table

According to Scott (2003), several monitoring wells are located around the Starr C&D Landfill. The average depth to groundwater on the property is 35 feet, while the wells next to streams average 15 feet to groundwater. And, the proposed site on the adjacent property has an average groundwater depth of 42 feet. All of these locations far exceed South Carolina regulations, which require that a minimum 2-foot separation from groundwater be maintained throughout the life of the compost facility.

Flood Plain

As described in Chapter 7, South Carolina law allows a compost facility to be located in a flood plain, but the facility cannot restrict the flow of the 100-year flood. According to Scott (2003), the proposed facility site is not located within a 100-year flood plain. Thus, together with a deep water table and proper grading, windrows constructed on this site should not be in jeopardy of anaerobic conditions caused by standing water.

Water Quality

South Carolina law prohibits the construction of any compost facility within 200 feet of streams and rivers. Additionally, compost facilities can be no closer than 100 feet from all drinking water wells. According to Scott (2003), no drinking water wells exist on the property. There is, however, a stream that runs along the property boundary, but on a site in excess of 90 acres, the compost facility could easily be located in an area greater than 200 feet from this stream. To limit the effects that future composting operations will have on the quality of surrounding surface and ground waters, proper runoff management must be emphasized prior to construction.

Area Requirements

This section will approximate land area requirements for both low and intermediate level composting facilities. The calculations concerning these requirements are based on Anderson County's current annual estimate of 20,000 tons of incoming yard waste. Although seasonal variations in yard waste generation rates may exists, the amount of incoming yard waste is assumed to be uniform throughout the year in order to provide a general approximation for the land area required.

Prior to commencing final facility design and construction activities, it is highly recommended that Anderson County initiate a comprehensive study to determine exact yard waste generation statistics. The findings of this data collection will confirm if any seasonal variability exists. And, if the data does not support a uniform distribution, as assumed for these calculations, alterations will need to be made to the general design criteria. This would entail a design able to accommodate the maximum amount of incoming yard waste for a given time frame. For example, designing for the maximum monthly load would be more accurate than designing for the year. Likewise, designing for the maximum weekly load would ensure a more capable facility than one designed for the maximum monthly load.

Low Technology Area Requirements

As introduced in Chapter 5, the low technology composting process constructs windrows approximately 6 feet high by 12 feet wide, which are turned 3 to 5 times per year using a front-end loader (Tchobanoglous *et al.*, 1993). After 10 to 11 months of composting, the pile can be moved to allow for final curing, thus freeing the original

location to accept new organic material. Using this procedure, cured compost can be produced in approximately 16 to 18 months (Strom and Finstein, 1989).

From Chapter 7, the land area required for a compost facility can be approximated as one acre for every 4,000 to 5,000 cubic yards of loose incoming yard waste (Daniel and Smith, 1992). In order to calculate this required area, Anderson County's yard waste estimates must first be converted from a mass to a volume. Thus, the density of yard waste must be known to accomplish this conversion. According to Taylor and Kashmanian (1988), the density of loose incoming yard waste ranges from 400 to 600 pounds per cubic yard. Thus, Equation 12.1 converts Anderson County's incoming yard waste estimates from mass to volume using the most conservative density value:

$$\left(\frac{20{,}000\,\text{tons}}{\text{year}}\right)\left(\frac{2{,}000\,\text{lbs}}{\text{ton}}\right)\left(\frac{\text{yd}^3}{400\,\text{lb}}\right) = 100{,}000\ \text{yd}^3/\text{year} \qquad (12.1)$$

The required land area for the Anderson County facility can then be estimated using the volume to area ratio from Daniel and Smith (1992) above and the volume of incoming yard waste calculated in equation 12.1:

$$\left(100{,}000\ \text{yd}^3\right)\left(\frac{\text{acre}}{4{,}000\ \text{yd}^3}\right) = 25\,\text{acres} \qquad (12.2)$$

It is important to note, however, that 25 acres may be a generous estimate for the required land area, given that infrastructure currently used to support operations at the Starr C&D Landfill can also be utilized to support composting operations. For instance, the scale used to weigh incoming loads can be shared, while an existing structure may be used to store equipment for both operations.

A more accurate estimate for land area can be calculated by designing a composting pad based on the maximum number of windrows requiring construction. This can be accomplished if the volume of each windrow is known. As stated above, typical low technology windrows are 6 feet high by 12 feet wide. Because these windrows are formed by a front-end loader, a hemispherical cross section can be assumed. The cross-sectional area of each windrow can then be calculated by using the equation for the area of a semicircle:

$$\frac{(\pi)(r^2)}{2} = \frac{(\pi)(6\,\text{ft})^2(\text{yd}^2)}{(2)(9\,\text{ft}^2)} = 6.28\,\text{yd}^2 \qquad (12.3)$$

The windrow length can now be calculated by dividing the incoming volume of yard waste by the cross-sectional area of the windrow. But, because Anderson County's incoming yard waste volume was calculated in terms of volume per year (see Equation 12.1 above), the following equation will convert the volume to a weekly basis, and thus calculate the average windrow length constructed each week:

$$\frac{\left(\dfrac{100{,}000\,\text{yd}^3}{\text{year}}\right)\left(\dfrac{\text{year}}{52\,\text{weeks}}\right)}{6.28\,\text{yd}^2} = 306\,\text{yd/week} \qquad (12.4)$$

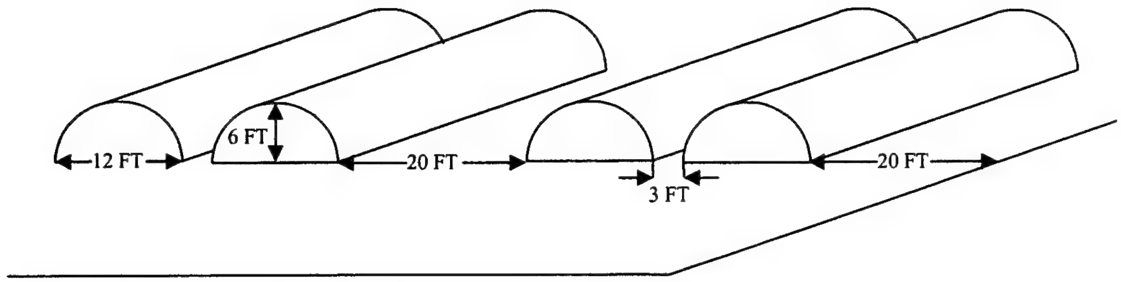
It is unrealistic to construct a single, 306 yard-long windrow each week. It is more likely that two windrows, both 153 yards in length will be constructed on the compost pad. Therefore, based on the current amount of incoming yard waste, the compost pad should be designed to a length of 170 yards – this will accommodate two windrows per week at 153 yards in length, while also providing sufficient space at each

end of the windrows for equipment maneuverability. The additional length will also accommodate fluctuations in weekly yard waste volumes.

Now that the length of the compost pad has been calculated, the width of the pad must be determined in order to calculate the pad area. But to accomplish this, the total number of windrows must be known. With the selection of the low-level technology, compost can be removed from the active pad in approximately 11 months. And, as stated previously, this design is based on creating two new windrows every week. Eventually, however, a steady state will be reached where the number of windrows being constructed will equal the number of windrows being removed. This steady-state value is the minimum number of windrows required to adequately calculate the compost pad width.

According to Strom and Finstein (1994), windrows will have reduced in size to approximately half their original volume through decomposition and self-compaction roughly one month after construction. At this point, the two windrows formed in the same week can be combined to form a single windrow that is about the same size as each of the initial windrows. For example, at the beginning of week 5, the two windrows constructed during week 1 are ready to be combined.

In this low technology scenario, constructing two windrows per week, steady state is ultimately reached in 44 weeks with 48 windrows. During week 45 of operations, the combined windrow from week 1 will be removed and transported to the curing pad. Additionally, the two windrows constructed in week 41 will be combined, in essence removing a second windrow from the pad. This removal of two windrows will counteract the construction of two windrows, thereby keeping the number of windrows constant at 48.



Figures 12.4 Low Technology Configuration of Windrows on Compost Pad

As Figure 12.4 illustrates, each of the 48 windrows is 12 feet wide at its base. Additionally, because the low technology method does not utilize specialized windrow turning equipment, two windrows can be formed side by side to conserve space, with only 3 feet between. Next, allow for a 20-foot wide aisle between each set of windrows to accommodate the front-end loader that will be used to mix the windrows. Allowances should also be made for a perimeter aisle between the edge of the compost pad and the first and last windrow, thus giving 25 aisles total. Accordingly, the required pad width is:

$$(48\,\text{windrows})(12\,\text{ft}) + (48\,\text{spacings})(3\,\text{ft}) + (25\,\text{aisles})(20\,\text{ft}) = 1{,}220\,\text{ft} = 407\text{ yd} \quad (12.5)$$

Therefore, the land area required for the compost pad can be calculated as:

$$(170\,\text{yd})(407\,\text{yd}) = 69{,}190\,\text{yd}^2 = 14.3\,\text{acres} \quad (12.6)$$

Finally, to determine the total area requirements, Richard *et al.* (1990) recommend sizing the staging and curing areas each at one-quarter of the size required for the compost pad, while the post-processing area should be sized at approximately

one-fifth the area of the compost pad. Hence, the area requirement for the staging and curing areas would be:

$$(14.3\,\text{acres})(0.25) = 3.6\,\text{acres} \tag{12.7}$$

Similarly, the area required for the post-processing area can be calculated as:

$$(14.3\,\text{acres})(0.20) = 2.9\,\text{acres} \tag{12.8}$$

Table 12.1 provides a summary of the total land area required for Anderson County's composting operation based on low technology processing. This table shows a total land area requirement of 24.4 acres, which is very similar to the previously estimated value of 25 acres. These two values would have been nearly identical, had allowances been made in the calculated value for structures to house administrative and equipment storage and maintenance functions. As previously mentioned, however, it is quite likely that the proposed composting operation will make use of current structures (e.g., scales, administrative offices, and covered storage for equipment).

Table 12.1

Low Technology Land Area Requirements

Operation	**Area Required (acres)**
Active Compost Pad	14.3
Staging Area	3.6
Curing Area	3.6
Post-Processing Area	2.9
Total	**24.4**

Intermediate Technology Area Requirements

The intermediate-level approach to composting requires that windrows be turned twice per week at the onset, then curtailing to one turning per week (Strom and Finstein, 1989). Following this approach, fully cured compost can be produced in approximately 4 to 6 months (Tchobanoglous *et al.*, 1993). With the frequent mixing required from the intermediate-level approach, turning with a front-end loader becomes impractical. Consequently, specialized windrow turning machines should be used. Although additional equipment is required, this method produces a mature product in about half the time it would take using the low technology method, yielding a significant reduction in overall land requirements.

As with the low technology scenario, the land area required for an intermediate technology method can be approximated as one acre for every 4,000 to 5,000 cubic yards of loose incoming yard waste. However, this estimate is based upon the low-level technology, which requires approximately one year to generate a viable product (Strom, 2003). Because this intermediate-level technology produces mature compost in approximately 6 months (2 compost cycles per year), only half of Anderson County's incoming yard waste estimate should be used to approximate a suitably sized compost facility. Subsequently, Equation 12.9 calculates Anderson County's incoming yard waste estimates in terms of volume per compost cycle:

$$\left(\frac{20{,}000\,\text{tons}}{\text{year}}\right)\left(\frac{\text{year}}{2\,\text{cycles}}\right)\left(\frac{2{,}000\,\text{lbs}}{\text{ton}}\right)\left(\frac{\text{yd}^3}{400\,\text{lb}}\right)=50{,}000\,\text{yd}^3/\text{cycle} \qquad (12.9)$$

The required land area for the intermediate technology can then be estimated as it was for the low technology method in Equation 12.2:

$$\left(50{,}000\,\text{yd}^3\right)\left(\frac{\text{acre}}{4{,}000\,\text{yd}^3}\right) = 12.5\,\text{acres} \tag{12.10}$$

Similar to the low technology design, the land area estimated in Equation 12.10 should be compared to a more thorough area calculation based on the maximum number of windrows requiring construction. But, because windrow volumes using the intermediate technology are dependent upon the type and model of windrow turner used, an accurate design cannot be accomplished until a specific model has been selected. This design will assume the Wildcat TS 514 compost turner is used, as it is well suited to handle the volume of Anderson County's incoming yard waste. The Wildcat TS 514 will construct windrows with a cross-sectional area resembling a trapezoid, having a bottom width of 14 feet, a top width of 4 feet, and a height of 5 feet (Waltner, 2003). The cross-sectional area of each windrow can then be calculated by using the equation for the area of a trapezoid:

$$\frac{(5\,\text{ft})(14\,\text{ft} + 4\,\text{ft})}{2} = \left(45\,\text{ft}^2\right)\left(\frac{\text{yd}^2}{9\,\text{ft}^2}\right) = 5\,\text{yd}^2 \tag{12.11}$$

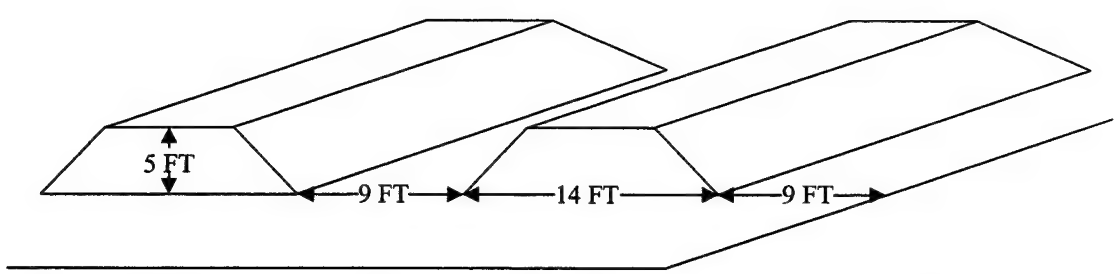
Next, the windrow length is calculated as before in Equation 12.4:

$$\frac{\left(\dfrac{50{,}000\,\text{yd}^3}{\text{cycle}}\right)\left(\dfrac{\text{cycle}}{26\,\text{weeks}}\right)}{5\,\text{yd}^2} = 384.62\,\text{yd/week} \tag{12.12}$$

As with the low technology method, constructing a windrow in excess of 300 yards each week is impractical. Instead, the pad will be designed on the basis that two windrows, both 192 yards in length will be constructed per week. Therefore, the

intermediate level compost pad should be designed to a length of 215 yards. Like the low technology design, this additional length will provide sufficient space at each end of the windrows for equipment maneuvering and minor fluctuations in incoming yard waste.

The width of the pad must now be determined in order to calculate the total pad area. As with the low technology approach, windrows will eventually reduce to half their original size, allowing two windrows formed in the same week to be combined. In this scenario, constructing two windrows per week, steady state is ultimately reached in 16 weeks with 20 windrows. During the 17th week of operation, the combined windrow from the 1st week will be removed and transported to the curing pad. Additionally, the two windrows constructed in the 12th week will be combined, resulting in the net removal of two windrows from the compost pad. The removal of two windrows counterbalances the construction of two windrows, keeping the number of windrows constant at 20.



Figures 12.5 Intermediate Technology Configuration of Windrows on Compost Pad

Figure 12.5 shows the configuration of windrows on the compost pad using intermediate technology. Each of the 20 windrows is 14 feet wide at their base, separated

by 9-foot-wide aisles to satisfactorily accommodate the front-end loader used to tow the compost turning machine. With these values, a pad width can be calculated by allowing for 21 aisles, including perimeter aisles between the edge of the compost pad and the first and last windrows. Accordingly, the required pad width is:

$$(20\,\text{windrows})(14\,\text{ft}) + (21\,\text{aisles})(9\,\text{ft}) = 469\,\text{ft} = 157\,\text{yd} \tag{12.13}$$

Therefore, the land area required for the compost pad can be calculated as:

$$(215\,\text{yd})(157\,\text{yd}) = 33{,}755\,\text{yd}^2 = 7\,\text{acres} \tag{12.14}$$

Lastly, the total area requirements can be calculated by approximating the staging, curing, and post-processing areas as was done in Equations 12.7 and 12.8. Consequently, the area requirement for the staging and curing areas is:

$$(7\,\text{acres})(0.25) = 1.75\,\text{acres} \tag{12.15}$$

Similarly, the area required for the post-processing area can be calculated as:

$$(7\,\text{acres})(0.20) = 1.4\,\text{acres} \tag{12.16}$$

Table 12.2 summarizes the total land area required for Anderson County's composting operation utilizing the intermediate technology approach. This table shows a total land area requirement of nearly 12 acres, bringing validity to the previously estimated value of 12.5 acres. As with the low technology approach, this design assumes structures currently supporting C&D landfill operations can also be used to support the needs of a composting operation.

Table 12.2

Intermediate Technology Land Area Requirements

Operation	Area Required (acres)
Active Compost Pad	7.00
Staging Area	1.75
Curing Area	1.75
Post-Processing Area	1.40
Total	**11.9**

Site Preparation

Regardless of the technology selected to process incoming yard waste, the chosen site must first be cleared and graded in preparation for composting operations. The price of this preparation is highly dependent upon the chosen technology. R.S. Means (2002) estimates approximately \$1,000 per acre for clearing and grubbing operations, while grading for large areas will cost \$0.76 per square yard. As calculated previously, the estimated land area required for low and intermediate technology approaches is 24.4 acres and 11.9 acres, respectively. Consequently, the estimated cost to clear and grub 24.4 acres using the low technology approach is:

$$(24.4\,\text{acres})\left(\frac{\$1{,}000}{\text{acre}}\right) = \$24{,}400 \tag{12.17}$$

Grading a 24.4 acre site is estimated as:

$$(24.4\,\text{acres})\left(\frac{4{,}840\,\text{yd}^2}{\text{acre}}\right)\left(\frac{\$0.76}{\text{yd}^2}\right) = \$89{,}753 \tag{12.18}$$

Likewise, the cost to clear and grub 11.9 acres using the intermediate approach is:

$$(11.9\,\text{acres})\left(\frac{\$1{,}000}{\text{acre}}\right) = \$11{,}900 \tag{12.19}$$

Grading for the 11.9 acre site is estimated as:

$$(11.9\,\text{acres})\left(\frac{4{,}840\,\text{yd}^2}{\text{acre}}\right)\left(\frac{\$0.76}{\text{yd}^2}\right) = \$43{,}773 \tag{12.20}$$

As mentioned in Chapter 7, a low level approach will not likely require paving. Hence, leachate and runoff is typically managed by creating a grass filter strip. If, however, an intermediate approach is selected, paving of the compost pad may be preferred over an earthen pad, as it provides a better surface for more efficient operation of specialized turning machinery. And, while several different paving options were discussed in Chapter 7, this section will examine the costs associated with an asphalt surface, which is more durable than a lime-stabilized pad and decidedly less expensive than concrete. According to Shelato (2003), 7 acres paved with 6 inches of stone base, followed by 2.5 inches of binder course and a 1.5 inch asphalt overlay will cost \$457,380.

At nearly half a million dollars, paving costs may appear to be prohibitive. But, as mentioned previously, one option to reduce the high cost of paving is to implement partial paving of the active compost pad. This method will allocate unpaved space for windrows, while allowing for the composting equipment to have year round access to the windrows via paved perimeters and aisles. The cost to partially pave the 7-acre pad can be estimated by first determining a unit price for asphalt paving from Shelato (2003):

$$\frac{\$457{,}380}{7\text{ acres}} = \$65{,}340\text{ per acre} \tag{12.21}$$

Recalling that the intermediate approach will reach steady state with 20 windrows (each 14 feet wide and 192 yards long), the area to be paved can be determined by calculating the total area occupied by the windrows and subtracting that value from the total pad area of 7 acres:

$$(20\text{ windrows})(14\text{ ft})(192\text{ yd})\left(\frac{\text{yd}}{3\text{ ft}}\right)\left(\frac{\text{acre}}{4840\text{ yd}^2}\right) = 3.7\text{ acres} \tag{12.22}$$

Consequently, the cost to partially pave the 7-acre pad using asphalt is estimated as:

$$(7\text{ acres} - 3.7\text{ acres})\left(\frac{\$65{,}340}{\text{acre}}\right) = \$215{,}622 \tag{12.23}$$

Although partial paving can potentially save Anderson County over $240,000 in paving expenses, a more substantial collection system will be required to handle the larger volumes of runoff and leachate produced, regardless of which paved surface is selected.

R.S. Means (2002) estimates that excavating for a storm water detention basin will cost approximately $2 per cubic yard. However, in order to estimate a total price for constructing a detention basin, the required volume must be known. Developers typically use the 25-year, 1-day storm event to calculate required volumes, but this information could not be obtained for the Starr C&D Landfill. Alternatively, data were retrieved from the Anderson County airport to determine the most severe storm event for the region over a 24-hour period. Since 1948, the maximum precipitation for Anderson County occurred on July 18, 1964, when 6.94 inches fell over a one-day period (Southeast Regional

Climate Center, 2003). Consequently, this simple approximation assumes a worst-case scenario that requires a detention basin large enough to capture 6.94 inches of rain falling on 7 acres of impermeable asphalt over a 24-hour period. Based on this assumption, the approximate cost to construct a detention basin for a fully paved pad would be:

$$(7\,\text{acres})(6.94\,\text{inches})\left(\frac{4840\,\text{yd}^2}{\text{acre}}\right)\left(\frac{\text{yd}}{36\,\text{inches}}\right)\left(\frac{\$2}{\text{yd}^3}\right) = \$13{,}063 \qquad (12.24)$$

Similarly, the approximate cost to construct a detention basin based on partial paving would be:

$$(7\,\text{acres} - 3.7\,\text{acres})(6.94\,\text{inches})\left(\frac{4840\,\text{yd}^2}{\text{acre}}\right)\left(\frac{\text{yd}}{36\,\text{inches}}\right)\left(\frac{\$2}{\text{yd}^3}\right) = \$6{,}158 \qquad (12.25)$$

Furthermore, Shelato (2003) states that $5,000 should be added to the cost of excavation in order to accommodate the installation of an impermeable basin lining, bringing the total cost of a detention basin for a paved and partially paved surface to approximately $18,000 and $11,150, respectively.

Site Layout

Figure 12.6 illustrates a typical site layout for a compost facility. This configuration is valid for both low and intermediate technology approaches, as it provides for the logical and efficient flow of materials from the staging of incoming feedstock through the storing of finished product. The direction of the windrows is parallel to the slope, ensuring no excess moisture buildup within the windrows. Although not depicted, accommodations should be made for a buffer zone adjacent to the perimeter of the composting facility. As discussed in Chapter 7, a 1,000-foot buffer zone is highly

recommended between the facility and the nearest dwellings (Strom and Finstein, 1994). This buffer zone will counter the increased potential of odor problems caused by grass clippings, and can be easily satisfied if Anderson County sites the composting facility well within the proposed property boundaries.

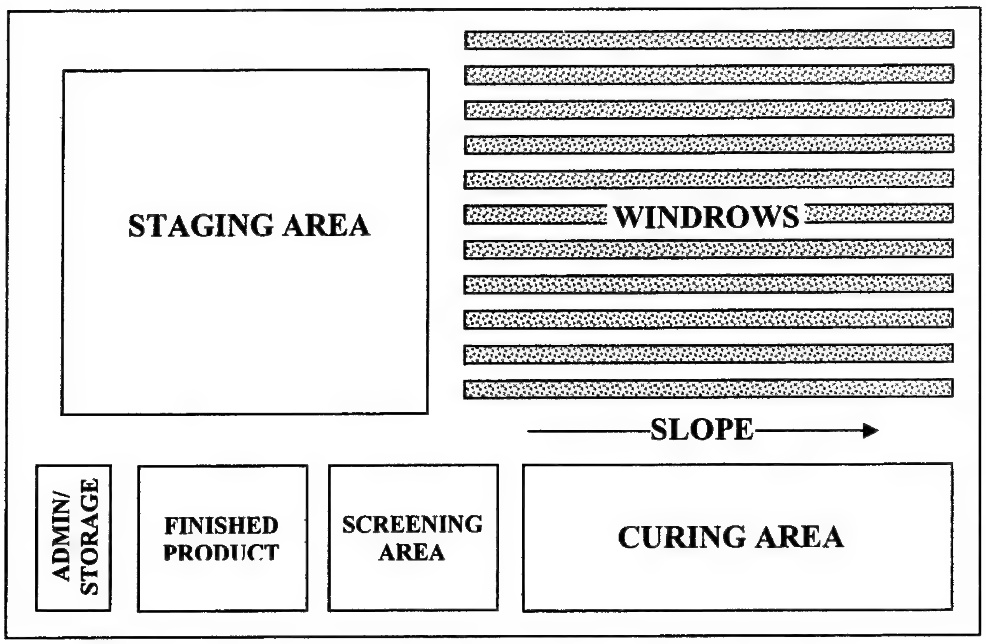


Figure 12.6 Typical Site Layout for a Compost Facility

Equipment Requirements and Costs

Whereas Chapter 6 provided a general overview of the major types of equipment typically encountered at a municipal yard waste composting facility, this section intends to provide specific recommendations for the heavy equipment required for Anderson County's compost operation, including purchase costs and rough approximations for operation and maintenance costs. Note that actual operating and maintenance costs could

vary considerably with the type of material being processed, maintenance practices, current market price of diesel fuel and level of care demonstrated by the operators.

Front-End Loader

The Caterpillar Model IT28G is an example of a suitable sized front-end loader for municipal composting applications. It offers strong hydraulics and allows for the interchangeability of work tools, making it a versatile workhorse. This machine typically sells for $125,000, but purchase price may vary depending on tools and options selected. In addition, the cost to operate and maintain this front-end loader is estimated to be $6,250 per year[1] (Caterpillar Inc., 2003).

As previously discussed, front-end loaders are ubiquitous to all composting operations, regardless of technology utilized. If quality of the end product was not a primary consideration, the low technology approach would only require the use of a front-end loader to form and turn the windrows. In practice, however, most compost facilities utilize grinders and screens in order to produce a consistently reliable product with high marketability. Subsequently, these two pieces of equipment are recommended for both technology levels discussed in this chapter.

Tub Grinder

A tub grinder suitable for Anderson County's current amount of incoming yard waste is the DiamondZ Model 1248B. With a 12-foot diameter tub and 20 hammermills at 40 pounds each, the Model 1248B can grind up to 60 tons of yard waste per hour at a purchase price of $285,000 (Malone, 2003). Additionally, grinders require regular

[1] Annual operating cost could not be gained directly from manufacturer. Cost based on 5 percent of purchase price, which is the average value for all other compost vehicles considered in this section.

maintenance, including rotation and replacement of the hammers (May and Simpson, 2003), making the average cost to maintain the Model 1248B approximately \$52 per hour of operation (Malone, 2003). Based on Anderson County's estimate of 20,000 tons of incoming yard waste per year, the likely cost to operate the Model 1248B will be:

$$\left(\frac{20{,}000\,\text{tons}}{\text{year}}\right)\left(\frac{\text{hour}}{60\,\text{tons}}\right)\left(\frac{\$52}{\text{hour}}\right) = \$17{,}333\ \text{per year} \qquad (12.26)$$

Trommel Screen

A trommel screen appropriately sized to handle Anderson County's compost production would be the Wildcat RHC 5-70. This particular model can accommodate 50 cubic yards of compost per hour and comes with folding conveyors. One conveyor captures screened compost, subsequently stacking the compost beside the machine. The second conveyor captures oversized materials (e.g., wood chips) that have passed through the trommel screen, stacking it on the opposite side of the machine from the screened compost. The RHC 5-70 has a list price of \$89,500 and a total estimated hourly operating cost of \$3.66 (Waltner, 2003).

According to the manufacturer, the RCH 5-70 is rated at 50 cubic yards per hour with a half inch screen installed (Waltner, 2003). As previously calculated, 20,000 tons of incoming yard waste can equate to 100,000 cubic yards. Miller (2000) states that yard waste compost will reduce in volume by approximately 40 to 75 percent overall. In order to calculate the maximum operating time for the trommel screen, it should be assumed that the overall volume of yard waste is reduced by only 40 percent, resulting in an estimated 60,000 cubic yards of finished compost to screen on an annual basis. Subsequently, the annual cost to operate the RCH 5-70 can be estimated as:

$$\left(\frac{60{,}000\,\text{yd}^3}{\text{year}}\right)\left(\frac{\text{hour}}{50\,\text{yd}^3}\right)\left(\frac{\$3.66}{\text{hour}}\right) = \$4{,}392\,\text{per year} \tag{12.27}$$

Windrow Turner

The sole piece of equipment that distinguishes the intermediate level approach from the low level approach is the windrow turning machine. As introduced earlier in this chapter for design considerations, a suitable model for Anderson County is the Wildcat TS 514. This turner is towed behind a front-end loader and straddles the material, creating a 5 foot by 14 foot windrow in a single pass. This particular model has a list price of $78,000 with an estimated hourly operating cost of $14.89. According to the manufacturer, the TS 514 will operate approximately 200 hours per year on a 20,000 ton-per-year site, bringing the annual operating cost to $2,978 (Waltner, 2003).

Water Truck

As discussed in Chapter 6, if a utilities infrastructure is not integrated into the composting facility, a water truck is the likely alternative to ensure windrows maintain adequate moisture levels. Consequently, a water truck compatible with composting operations should have ample storage capacity (approximately 4,000 gallons) and side discharge nozzles to hydrate windrows while driving between them. A late-model truck can be found on the used market for approximately $50,000. Additionally, normal annual operating costs are expected to be negligible relative to other compost machinery.

Labor Requirements and Costs

At a minimum, three full-time employees – a facility supervisor and two equipment operators – will be required to adequately operate the proposed compost

facility. The facility supervisor is accountable for day-to-day operations, including material handling and sales as well as the monitoring, interpretation, and control of key process variables. The two equipment operators must be well versed in operating all facility equipment and performing simple maintenance procedures.

The municipal yard waste compost facility in nearby Rock Hill, South Carolina, can be used to approximate the annual manpower costs for Anderson County. Rock Hill budgets roughly $35,000 for a facility supervisor, while each equipment operator is compensated with an estimated $27,000 per year (Koven, 2003). Combined, the annual manpower costs for the Anderson County facility would be an estimated $89,000, which does not include any consideration for benefits or overtime.

Other required duties include municipal yard waste collectors and facility scale operators. These duties are currently being accomplished in support of existing county practices associated with the Starr C&D Landfill. As a result, these requirements should not generate any additional manpower costs in the event a compost operation is initiated.

Costs Summary and Profit Potential

This section reiterates the anticipated capital costs for the Anderson County compost facility, offering summaries of both low level and intermediate level technologies. Additionally, annual net revenue will be approximated by determining potential profits from the sale of compost and adjusting for expected operating costs.

Capital Costs

Table 12.3 summarizes the capital costs for both low and intermediate level facilities. Architectural and engineering (A/E) services were not included in this estimate. A/E support services will likely be necessary for activities such as

comprehensive site design, facility permits, construction oversight, and operation start-up. Costs of A/E services will vary depending upon the level of support required, but can be as much as 10 to 15 percent of the site improvement costs.

Table 12.3

Summary of Anticipated Capital Costs

Task	Low Level	Intermediate No Paving	Intermediate Partial Paving	Intermediate Full Paving
Site Improvements				
Clearing	$24,400	$11,900	$11,900	$11,900
Grading	$89,753	$43,773	$43,773	$43,773
Paving	N/A	N/A	$215,622	$457,380
Detention Basin	N/A	N/A	$11,150	$18,063
Equipment				
Front-End Loader	$125,000	$125,000	$125,000	$125,000
Tub Grinder	$285,000	$285,000	$285,000	$285,000
Water Truck	$50,000	$50,000	$50,000	$50,000
Windrow Turner	N/A	$78,000	$78,000	$78,000
Screener	$89,500	$89,500	$89,500	$89,500
Monitoring Equipment	$5,000	$5,000	$5,000	$5,000
Total Capital Costs	**$668,653**	**$688,173**	**$914,945**	**$1,163,616**

Barring paving and storm water management expenses, costs to implement the intermediate technology will be roughly $19,500 greater than the low level technology. Although more expensive, the intermediate level approach will utilize 12.5 acres less than the low level facility, offering greater opportunity for future expansion of adjacent C&D

landfill operations. Additionally, the intermediate level technology is better suited for handling large amounts of grass clippings (Strom and Finstein, 1989).

Profit Potential

Post-processing techniques (e.g., screening) will result in compost and mulch, both of which are highly marketable commodities. Based on Anderson County's annual estimate of incoming yard waste, gross revenue from the sale of these products can be approximated. First, however, several broad assumptions must be addressed. The first assumption deals with the expected reduction in volume of incoming feedstock. As stated previously, Miller (2002) estimates that yard wastes composted on a large scale can experience volume losses up to 75 percent. Accordingly, maximum reduction in volume is assumed in order to calculate a conservative revenue approximation. Additionally, because the actual composition of incoming yard wastes is not known, the resulting volumes of compost and mulch are assumed to be equal. Based on these assumptions, 100,000 cubic yards (20,000 tons) of incoming yard waste results in a total output of 25,000 cubic yards, or 12,500 cubic yards of compost and mulch, respectively.

Several compost facilities in North Carolina, South Carolina, and Virginia were queried to determine their retail pricing structure for compost and mulch. For compost, reported prices ranged from \$12 to \$24 per cubic yard, with \$24 per cubic yard being the most consistent response. Mulch prices ranged from \$7 to \$10 per cubic yard, with the most consistent price being \$7 per cubic yard. Thus, it is reasonable to assume that Anderson County could effectively charge \$24 per cubic yard for their compost and \$7 per cubic yard for their mulch. Subsequently, revenue from compost sales would be:

$$\left(\frac{12{,}500\,\text{yd}^3\text{ compost}}{\text{year}}\right)\left(\frac{\$24}{\text{yd}^3}\right) = \$300{,}000\,\text{per year} \tag{12.28}$$

Similarly, the approximated revenue from the sale of mulch would be:

$$\left(\frac{12{,}500\,\text{yd}^3\text{ mulch}}{\text{year}}\right)\left(\frac{\$7}{\text{yd}^3}\right) = \$87{,}500\,\text{per year} \tag{12.29}$$

Therefore, based on the product yields estimated above, the Anderson County facility could earn a gross revenue of approximately $387,500 per year.

Table 12.4

Summary of Anticipated Net Revenue

Description	Annual Revenue/Operating Costs Low Level	Intermediate Level[1]
Gross Revenue	$387,500	$387,500
Manpower	-$89,000	-$89,000
Equipment		
Front-End Loader	-$6,250[2]	-$6,250[2]
Tub Grinder	-$17,333	-$17,333
Water Truck	Negligible	Negligible
Windrow Turner	N/A	-$2,978
Screener	-$4,392	-$4,392
Laboratory Testing	-$2,000	-$2,000
Net Revenue	**$268,525**	**$265,547**

[1]Independent of compost pad surface type.
[2]Based on an average operating to purchase cost ratio of 5 percent.

Table 12.4 summarizes the net revenue for the compost facility by accounting for all expected annual operating costs. As the table indicates, both low level and

intermediate level technologies can generate a net revenue in excess of \$265,000 based on current yard waste estimates for Anderson County. This outcome also assumes that all capital costs were provided at the onset. The period required to repay these capital investments must not be overlooked before true net profits are realized. Accordingly, the payback period for the low technology facility is:

$$\frac{\$668{,}653 \text{ capital investment}}{\$268{,}525 \text{ per year}} = 2.5 \text{ years} \tag{12.30}$$

Likewise, the payback period for the intermediate facility without paving is:

$$\frac{\$688{,}173 \text{ capital investment}}{\$265{,}547 \text{ per year}} = 2.6 \text{ years} \tag{12.31}$$

And, the payback period for the intermediate facility with partial paving is:

$$\frac{\$914{,}945 \text{ capital investment}}{\$265{,}547 \text{ per year}} = 3.4 \text{ years} \tag{12.32}$$

Finally, the payback period for the intermediate facility with paving is:

$$\frac{\$1{,}163{,}616 \text{ capital investment}}{\$265{,}547 \text{ per year}} = 4.4 \text{ years} \tag{12.33}$$

If, however, financing is required for equipment acquisition and facility construction (as is often the case with private business ventures), amortization of these capital costs will produce a more accurate estimate of annual net revenue. To amortize these capital costs, an interest rate of 8 percent is assumed over a period of 12 years, which is a typical lifespan for compost machinery. Although the lifespan of an asphalt

surface may reach 20 years, this scenario will spread the cost of all capital investments over a 12-year period for sake of simplicity. Consequently, using the total capital costs from Table 12.3, the annual cost for low technology capital expenses is calculated as:

$$(\$668{,}653)\left[\frac{0.08(1.08)^{12}}{(1.08)^{12}-1}\right]=\$88{,}726 \tag{12.34}$$

Similarly, the amortized cost for intermediate level capital expenses without paving is:

$$(\$688{,}173)\left[\frac{0.08(1.08)^{12}}{(1.08)^{12}-1}\right]=\$91{,}317 \tag{12.35}$$

And, the amortized cost for intermediate level capital expenses with partial paving is:

$$(\$914{,}945)\left[\frac{0.08(1.08)^{12}}{(1.08)^{12}-1}\right]=\$121{,}409 \tag{12.36}$$

Lastly, the amortized cost for intermediate technology capital expenses with full paving is:

$$(\$1{,}163{,}616)\left[\frac{0.08(1.08)^{12}}{(1.08)^{12}-1}\right]=\$154{,}406 \tag{12.37}$$

The resulting net revenues associated with amortized capital costs are summarized in Table 12.5.

Table 12.5

Net Revenue Assuming Amortized Capital Costs

Description	**Low Level**	**Intermediate No Paving**	**Intermediate Partial Paving**	**Intermediate Full Paving**
Gross Revenue	$387,500	$387,500	$387,500	$387,500
Operating Costs[1]	-$118,975	-$121,953	-$121,953	-$121,953
Amortized Capital Costs	-$88,726	-$91,317	-$121,409	-$154,406
Net Annual Revenue	**$179,799**	**$174,230**	**$144,138**	**$111,141**

[1]Summation of anticipated annual operating costs from Table 12.4.

Whether the capital costs are paid upfront or amortized over a specified period of time, both scenarios illustrate the potential for the proposed Anderson County compost operation to generate substantial revenue. It is important to note, however, that actual outcomes are highly dependent upon the amount and composition of incoming feedstock, the overall volume reduction, and the ability to develop and maintain a viable compost market.

Influence of Source Reduction on Revenue

In addition to the factors listed above, source reduction efforts may also drastically influence Anderson County's ability to produce sufficient revenue. As discussed in Chapter 9, reducing the amount of grass clippings entering a compost facility will lower the potential for odor problems, but how will this influence revenue generation? In an effort to quantify this effect, gross revenue for Anderson County will be recalculated based on a 50 percent reduction in the amount of grass clippings entering the waste stream during the active growing season. To accomplish this, several assumptions must be addressed. First, the active growing season for grass is assumed to

occur between April and September. Next, assume that grass clippings currently constitute 50 percent of the total yard waste collected during the active growing season. As with the land area approximations, it is also assumed that the active growing season has uniform yard waste generation rates relative to the entire year. Consequently, the total amount of incoming yard waste for this 6-month period is assumed to be 10,000 tons. Based on these assumptions, the amount of grass clippings included in the total yard waste during the active growing season can be calculated as:

$$(10{,}000 \text{ tons yard waste})(50\% \text{ grass clippings}) = 5{,}000 \text{ tons of grass clippings} \qquad (12.38)$$

Subsequently, the annual reduction in yard waste is approximated as:

$$(5{,}000 \text{ tons grass clippings})(50\% \text{ source reduction}) = 2{,}500 \text{ tons per year} \qquad (12.39)$$

Next, the annual reduction in incoming yard waste on a volumetric basis is estimated as:

$$(2{,}500 \text{ tons})\left(\frac{2{,}000 \text{ lb}}{\text{ton}}\right)\left(\frac{\text{yd}^3}{400 \text{ lb}}\right) = 12{,}500 \text{ yd}^3 \qquad (12.40)$$

Because grass clippings will only contribute to the production of compost and not to mulch, the reduction in grass clippings must be subtracted from that fraction of incoming yard waste resulting solely in compost. As mentioned previously in this chapter, because the actual composition of incoming yard waste for Anderson County is unknown, it is assumed that of the 100,000 cubic yards of yard waste entering Anderson County's facility each year, 50,000 cubic yards of that yard waste will contribute to the production of compost. As a result, the adjusted volume of incoming yard waste contributing to compost production is:

$$50{,}000\ \text{yd}^3 - 12{,}500\ \text{yd}^3 = 37{,}500\ \text{yd}^3 \tag{12.41}$$

But, yard waste can experience a 75 percent reduction in volume during the active composting process (Miller, 2002). Accordingly, the amount of cured compost produced per year resulting from the source reduction of grass clippings can be approximated as:

$$\left(37{,}500\text{yd}^3\right)\left(0.25\right) = 9{,}375\ \text{yd}^3 \text{ of compost} \tag{12.42}$$

Similar to equation 12.28, revenue from compost sales can now be approximated:

$$\left(\frac{9{,}375\ \text{yd}^3\ \text{compost}}{\text{year}}\right)\left(\frac{\$24}{\text{yd}^3}\right) = \$225{,}000\,\text{per year} \tag{12.43}$$

Mulch volumes would remain unchanged, resulting in $87,500 per year in potential revenue, as calculated in equation 12.29. Thus, the total potential revenue following a 50 percent reduction in grass clippings would be $312,500 – a loss of $75,000 per year when compared to the original gross revenue approximation of $387,500 per year. This decrease in net revenue will be considerable. Compared to the profits summarized in Table 12.5, the reduction in net revenue ranges from 42 percent for the low level facility to 67 percent for the intermediate level facility with full paving.

CHAPTER 13

CONCLUSIONS

The ultimate goal of this research was to investigate the principal aspects of planning, constructing, and operating a municipal yard waste composting facility for Anderson County, South Carolina. Accordingly, this chapter summarizes the conclusions drawn from this research.

It is highly recommended that Anderson County initiate a comprehensive study to determine annual yard waste generation statistics prior to the final design of a municipal composting facility. The data collected from this study will determine if any seasonal variability exists, allowing for the design of a facility that can sufficiently accommodate the maximum amount of incoming yard waste for a given time frame. Only then, after this data has been incorporated into a suitable design, should construction commence at an appropriate location.

One such location is the land adjacent to the Starr C&D Landfill. Not only does it have the site characteristics required by regulation, but because the proposed composting site is adjacent to Anderson County's current yard waste disposal site, it will not generate increased transportation costs. Another important consideration that makes this site appealing is its remoteness from residential neighborhoods. Nevertheless, a good composting operation is not based solely on the location of the facility.

Because yard waste composting is fundamentally a microbiological conversion of raw organic waste into a soil-enriching end product, understanding the connection

between this microbial activity and its associated physical parameters is imperative to any successful operation. By meeting optimal conditions required by the microorganisms responsible for biodegradation, Anderson County should effectively and consistently produce high quality compost, while preventing common operating problems. And, since Anderson County intends to incorporate grass clippings into its proposed composting operation, an intermediate level technology with a dedicated windrow turning machine is recommended to ensure these optimal conditions are met. Although this approach is more expensive in terms of capital costs when compared to the low level technology, it requires considerably less land and produces a viable product in a fraction of the time.

With a well-understood and well-managed process, coupled with a campaign to educate consumers on the many benefits of compost, the potential exists for Anderson County to generate substantial revenue from sales. If required, county agencies can act as contingency consumers, using compost for public applications if the supply should exceed the demand set forth by private residents, landscapers, and nurseries. Regardless, it is ill-advised for Anderson County to initiate compost sales prior to participation in a testing program. Only then, after certified testing has deemed the compost safe for its intended uses, can the county ensure its residents receive the highest quality product.

Although municipal yard waste composting operations can yield a positive image and may even encourage participation in other recycling programs, the ultimate goal of any municipality should be to drastically reduce the generation of yard waste, thereby lessening the requirement for compost programs. While this may diminish the revenue associated with compost operations, savings may be attained through minimized collection costs. Accordingly, Anderson County should devise and implement public

awareness campaigns aimed at encouraging backyard composting and grass recycling programs. This campaign could also consider assessing fees for continued generation, thus providing an incentive for source reduction.

Ultimately, while it may be possible to control the generation of yard waste through public education, it is not likely that yard waste production will soon cease. In the meantime, composting exists as a practical and, in the case of Anderson County, an apparently cost-effective alternative to landfilling.

APPENDICES

Appendix A

Site Visits

Three municipal compost facilities were visited in the course of this research, each employing different levels of technology. Accordingly, in an effort to contrast the effectiveness of various compost technologies, this section provides a brief summary of the observed processes at each of these facilities.

Rock Hill, South Carolina

June 18, 2003

Located in York County, South Carolina, the Rock Hill facility was recently recognized as the top composting program in the state for 2002 by the South Carolina Department of Health and Environmental Control. Additionally, the Rock Hill Compost Center is the first compost facility in the state to be permitted to use food waste in its procedure, although the incorporation of food wastes into the feedstock had not commenced at the time of the visit.

The Rock Hill Compost Center processes approximately 10,000 tons of yard waste annually, selling the resulting compost for $24 per cubic yard, while the remaining mulch is sold for $7 per cubic yard. The facility utilizes an intermediate technology, mixing windrows with a specialized compost turning machine. In addition to the windrow turner, the Rock Hill facility operates a horizontal grinder for size reduction, a trommel screen for final processing, a skid loader for day-to-day operations, a water truck to maintain proper windrow moisture levels, and a dump truck to collect yard waste from the horizontal grinder and subsequently form the windrows.

The intermediate technology employed at this site appeared quite effective at minimizing the production of foul odors. This result is beneficial for the facility, given that they are located in the midst of the city near residential areas. When asked if the facility ever experienced serious odor problems or associated complaints, the facility manager replied earnestly that odor problems are not encountered.

One imperfection worth noting at the Rock Hill facility was the lack of a paved surface for the compost pad. Because Rock Hill's compost facility is sited on top of a closed MSW landfill, paving the surface is not an option due to the uneven settling of the decomposing MSW below. Rock Hill's only option, therefore, is to operate on a natural, graded surface. Figure A-1.1 illustrates how the use of heavy equipment after excessive rain at the Rock Hill facility has seriously damaged the grading of the site. This situation creates severe channeling and ponding that prohibits further use of heavy machinery on and around windrows, significantly delaying the time it takes to produce a viable product.

Figure A-1.1 Effects of Excess Rain on Unpaved Surface at Rock Hill, SC

Georgetown County

June 19, 2003

The Georgetown County, South Caronlina, facility is, by far, the most technologically advanced site of the three visited. The facility's main priority is to compost 13,000 tons of municipal biosolids annually, but it also processes roughly 6,000 tons of yard waste each year. Georgetown County collects its treated sludge from the Murrells Inlet Wastewater Treatment Plant and the Pawleys Island Wastewater Treatment Plant and uses the yard waste mainly as a bulking agent for the decomposing biosolids. As with the Rock Hill facility, Georgetown County utilizes a grinder for size reduction of the yard waste and a trommel screen for post processing. The resulting compost is sold for $25 per ton.

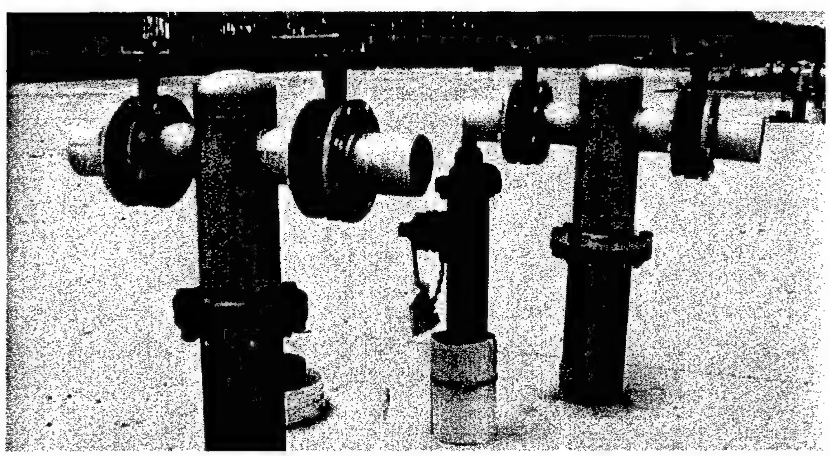


Figure A-1.2 Aerated Static Compost Pad at Georgetown County, SC

To facilitate the effective processing of nitrogen-rich biosolids, the Georgetown County facility utilizes a high level technology with static aerated piles. Figure A-1.2

illustrates the facility's concrete composting pad with associated aeration and hydration systems. The windrows are built atop perforated plastic tubing that is connected to the distribution nodes. Once the windrows are constructed, a network of fans and hydrants control the temperature and moisture content. Any resulting leachate is collected in centralized drains and returned to the local wastewater treatment plant for processing. After reaching and maintaining a required temperature range, the windrows then sit on the curing pad for 60 to 90 days. Once screened, the compost is analyzed by an independent laboratory to ensure the highest quality product.

During the site visit, composting operations were not underway due to a facility upgrade. Subsequently, the level of odors produced from this type of operation could not be assessed. Given the facility's rural location, it is doubtful that odors will become problematic once operations resume.

As discussed in Chapter 5, compost operations like the Georgetown County facility make little economic sense for municipalities that intend to compost yard waste as the sole feedstock. This suggestion is underscored by the cost data provided by Georgetown County. According to Wisikoski (2003), $2,100,000 was required to construct a forced aeration facility large enough to accommodate 19,000 tons of organic waste per year. Additionally, operating costs average approximately $78,000 per year, excluding costs for manpower (Wisikoski, 2003). Compare these figures to those anticipated for Anderson County in Chapter 12, recalling that Anderson County requires a facility large enough to accommodate 20,000 tons of organic waste per year. The most costly option proposed for Anderson County is an intermediate level facility with a fully paved composting pad. Estimated capital costs for this facility are approximately

$1,164,000. Furthermore, with the exception of manpower, operating expenses for the Anderson County facility are estimated to cost approximately $33,000 per year. Therefore, if Anderson County does not intend to compost problematic feedstocks such as biosolids or food waste, it is advantageous for county officials to select the intermediate level approach to composting. By doing so, the county can save nearly $1,000,000 in capital expenses and $45,000 per year in operating expenses.

Jacksonville, Florida

July 10, 2003

The Jacksonville compost facility is a privately-owned venture located in Duval County, Florida. It is the largest operation of the three visited, using a low level technology to process 40,000 tons of yard waste annually. In contrast to the Rock Hill and Georgetown County operations, the Jacksonville facility accepts no food wastes or biosolids, making yard waste (with large quantities of grass clippings) its sole feedstock. Similar to the former facilities, however, Jacksonville employs a grinder for size reduction, a trommel screen for final processing, and several front end loaders for day-to-day operations. The majority of the resulting compost is made available for free to Jacksonville residents, while any remainder is sold for commercial uses.

Figure A-1.3 shows the large windrows formed as a result of the low technology approach. The size of these windrows makes it very difficult to maintain aerobic conditions. As a result, a distinct and rancid odor was very apparent in the surrounding air. The site is located in a non-residential area, but is surrounded by other industrial activities. The facility manager denied ever receiving odor complaints from neighboring buildings, which was difficult to believe given the acute and objectionable odors. And,

not surprisingly, the facility manager said that his compost operations did not include any form of active odor control. With no odor control techniques employed and a technology level not conducive with the composting of grass clippings, it would not be presumptuous to assume that the Jacksonville facility could risk public opposition in the future.

Figure A-1.3 Low Technology Windrows at Jacksonville, FL

Appendix B

Equipment Manufacturers

Adapted from
May and Simpson (2003)

Shredders, Grinders, and Screeners

Aggregates Equipment Inc.
(screens)
PO Box 39
Leola, PA 17540-0039
(717) 656-2131
fax (717) 656-6686

Amadas Industries (screens)
PO Box 1833
Suffolk, VA 23434
(804) 539-0231
fax (804) 934-3264
www.amadas.com

Bandit Industries
(shredders/grinders/
used equipment)
6750 Mill Brook Rd.
Remus, MI 49340
(989) 561-2270
www.banditchippers.com

Banner Environmental
Recycling and Equipment
(screens, shredders)
N. 117 W. 18299 Fulton Dr.
Germantown, WI 53022
(262) 253-2900
fax (262) 253-2919
www.bannerweld.com

Construction Steel Inc.
(screens)
1772 Corn Rd.
Smyrna, GA 30080
(770) 433-2440

Diamond Z Manufacturing
(shredders/grinders)
11299 Bass Lane
Caldwell, ID 83605
(800) 949-2383
fax (208) 585-2112
www.diamondz.com

Excel Recycling &
Manufacturing Inc.
(screens, shredders/
grinders)
PO Box 31118
Amarillo, TX 79120
(800) 858-4002

EXTEC of North America
(screens, crushers/grinders)
Mailstop 32,
Tinicum Industrial Park,
No. 10 Industrial Hwy
Lefter, PA 19113
(610) 521-6344
fax (610) 521-5782
www.extescreens.com

Farmhand Inc.
(shredders/grinders)
Box 1500
Excelsior, MN 55331
(515) 236-6571

Fecon Inc.
(shredders/grinders)
10350 Evendale Dr.
Evendale, OH 45241
(513) 956-570
fax (513) 956-5701
(800) 528-3113
www.fecon.com

Fuel Harvesters Equipment
(shredders/grinders)
PO Box 7908
Midland, TX 79708
800) 622-7111
(915) 694-9988
fax (915) 694-9985

General Kinematics Corp.
(screener)
777 Lake Zurich Rd.
Barrington, IL 60010
(847) 381-2240
fax (847) 381-1376
www.generalkinematics.
com

Haybuster Manufacturing
(DuraTech Industries
International Inc.)
(grinders)
PO Box 1940
Jamestown, ND 58402
(701) 252-4601
fax (701) 252-0502
www.haybuster.com

Heil Engineered Systems
(shredders/grinders)
205 Bishops Way Suite 201
Brookfield, WI 53003
(262) 789-5530
fax (262) 789-5508
www.heil-engsys.com

Iggesund Recycling
(shredders/grinders)
PO Box 387
Aitkin, MN 56431
(218) 927-6922
fax (218) 927-6779

Jacobson Inc.
(shredders/grinders)
2445 Nevada Ave. N.
Minneapolis, MN 55427
(612) 544-8781

Jones Manufacturing Co.
(tub grinder)
PO Box 38
Beemer, NE 68716
(402) 528-3861
fax (402) 528-3239
www.mightygiant.com

Knight Industrial Division
PO Box 167
Brodhead, WI 53520
(608) 897-2131
fax (608) 897-2561

Lindemann Recycling
(screens)
500 Fifth Ave. Suite 1234
New York, NY 10110
(212) 382-0630

Lindig Manufacturing
PO Box 106
St. Paul, MN 55113
(612) 633-3072

MAC Corporation/
Salem Shredders
(shredders/grinders)
201 East Shady Grove Rd.
Grand Prairie, TX 75050
(214) 790-7800
fax (214) 790-8733

MI-JACK, (shredder)
3111 West 167th St.
Hazel Crest, IL 60429
(708) 596-5200
fax (708) 225-2312
www.mi-jack.com

Morbark Inc. (tub grinders,
chippers, screens)
PO Box 1000
Winn, MI
(800) 831-0042
www.morbark.com

Multitek
PO Box 170
Prentice, WI 54556-0170
(715) 428-2000
fax (715) 428-2700
(800) 243-5438
www.multitekinc.com

Norcia (shredders/grinders)
RD No 4, Box 451
North Brunswick, NJ 08902
(201) 297-1101

Northeast Implement Corp.,
West Salem Machinery Co.
PO Box 5288
Salem, OR 97304
(607) 589-6160
northeastimplement.com

Old Dominion Brush Co.
(shredders/grinders)
5118 Glen Alden Dr.
Richmond, VA 23231-4305
(800) 446-9823

Parker Manufacturing Inc.
18012 Bothell Highway SE
Bothell, WA 98012
(206) 486-3547

Powerscreen of America
(screens)
11300 Electron Dr.
Louisville, KY 40299
(502) 267-2314
fax (502) 267-2317

Processing & Recycling
Machinery (screener)
PO Box 26439
Eugene, OR 97402
(541) 689-1052
fax (541) 689-1052

Promark Products Inc.
330 9th Ave.
Industry, CA 91746
(818) 961-9783

Rawson Manufacturing Inc.
99 Canal St.
Putnam, CT 06260
(860) 928-4458
(860) 928-0366 fax
www.rawsonscreens.com

Re-Tech (screens)
341 King St.
Myerstown, PA 17067
(717) 866-2357
fax (717) 866-4710

Recomp Inc.
1500 East 79th St. Suite 102
Bloomington, MN 55420
(612) 854-6211

Read Corp. (screens)
25 Wareham St.
Middleboro, MA 02346
(800) 992-0145

Recycling Systems
PO Box 364
Winn, MI 48896
(517) 866-2800

Resource Recovery Systems
(screens)
PO Box 32035
Detroit, MI 48232
(519) 977-9852

Rexworks Inc.
(shredders/grinders)
445 W. Oklahoma Ave.
Milwaukee, WI 53207
(800) 292-6294
(414) 747-7200

Royer Industries,
(shredder/screener)
PO Box 1232
Kingston, PA 18704
(800) 44SHRED
(717) 287-9624

Satellite Screens
PO Box 366
DeWitt, IA 52742
(800) 922-2493
fax (319) 659-8387

Screening and Shredding
Systems
Winston-Salem, NC
(910) 766-6461

Screening Systems of
Virginia Inc.
PO Box 729
Lebanon, VA 24266
(540) 889-1400

Shredding Systems Inc.
(shredders/grinders)
PO Box 869
Wilsonville, OR 97070
(503) 682-3633
(800) 23-SHRED

Stumpmaster Inc.
(shredders/grinders)
PO Box 103
Rising Fawn, GA 30738
(404) 462-2445

Sundance
(shredders/grinders)
PO Box 2437
Greeley, CO 80632
(970) 339-9322
fax (970) 339-5856

Triple/S Dynamics Inc.
(shredders/grinders)
PO Box 151027
Dallas, TX 75315-1027
(214) 828-8600
fax (214) 828-8688
(800) 527-2116
www.sssdynamics.com

Universal Engineering
Division, Pettibone Corp.
(shredders/grinders)
800 First Ave. NW
Cedar Rapids, IA 52405
(319) 365-0441

Universal Refiner
Distributors Corp.
(shredders/grinders)
PO Box 125
Parlin, NJ 08859
(201) 525-1100

Valby Woodchippers
(shredders/grinders)
PO Box 402
Spencer, NY 14883
(607) 589-6160
fax (607) 589-4026

West Salem Machinery Co.
(screens, shredders/
grinders)
PO Box 5288
Salem, OR 97304
(503) 364-2213
(800) 722-3530

Wildcat Manufacturing Co.
(trommel screen)
PO Box 1100
Freeman, SD 57029
(800) 627-3954
fax (605) 925-7536

Compost Turners

Autrusa Compost
Consulting
(Sandberger)
PO Box 1133
Blue Bell, PA 19422
(215) 825-2973

Brown Bear Corp.
PO Box 29
Corning, IA 50841
(515) 322-4220
www.brownbearcorp.com

Eagle Crusher Co. Inc.
(Cobey)
PO Box 537
Galion, OH 44833
(800) 253-2453
fax (419) 468-4840
www.eaglecrusher.com

Fecon (Willibald)
9281 Le Saint Dr.
Farifield, OH 45014
(800) 528-3113
fax (513) 874-2914
www.fecon.com

Frontier Manufacturing Co.
192 Young St.
Woodburn, OR 97305
(503) 982-2907
(503) 982-5449

Kolman/Athey
PO Box 806
Sioux Falls, SD 57101
(605) 336-2610

Midwest Bio-Systems
(Sandberger)
28933-35 E St.
Tampico, IL 61283
(800) 335-8501
fax (815) 438-7028

Resource Recovery Systems
of Nebraska Inc
Rt. 4
Sterling, CO 80751
(970) 522-0663
fax (970) 552-3387
www.rrskw.com

Scarab Manufacturing
PO Box 1047
White Deer, TX 79097
(806) 883-7621
fax (806) 883-6804
www.scarabmfg.com

Scat Engineering
202 Locust
PO Box 237
Hopkinton, IA 52237
(800) 843-7228
fax (563) 926-9098
www.scat.com

Wildcat Manufacturing Co.
PO Box 1100
Freeman, SD 57029
(800) 627-3954
fax (605) 925-7536

Thermometers

Commonwealth Industrial
Specialists
2817 N. Parham Road
Richmond, VA
(804) 270-5018

Meriden Cooper Corp.
112 Golden State Park
Meriden, CT 06450
(203) 237-8448
www.meridencooper.com

Omega Engineering Inc.
1 Omega Drive
Stamford, CT 06907
(203) 359-1660
www.omega.com

Reotemp Instrument Corp.
11568 Roselle Street #10
San Diego, CA 92121
(619) 481-7737
(800) 648-7737

Trend Instrument Inc.
887 S. Matlock Street
PO Box 2047
West Chester, PA 19380
(215) 431-2000

Walden Instrument Supply
910 Main Street
Wakefield, MA 01880
(617) 245-2944

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